COLLECTED WORK NO. 4

PROJECTED CHARACTERISTICS OF LARGE COAL LIQUEFACTION COMPLEXES

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I. INTRODUCTION

We appreciate the opportunity to discuss with you today some elements of our judgmental concepts regarding general characteristics of large industrial complexes that might be constructed to produce "clean" liquid fuels from coal. We emphasize that at this stage of development these are judgmental concepts toward plant definition and economics; they are subject to confirmation when we have completed detailed studies and designs.

While our input to the Project Independence Blueprint (PIB) program was prepared under short deadline pressure, the results represent a distillation of the knowledge and experience gained during the course of approximately two years of performance during which The Ralph M. Parsons Company began our current role as Technical Evaluation Contractor for the Office of Coal Research (OCR). We gratefully acknowledge the support and guidance provided by OCR during the course of our work.

During this time Parsons has essentially completed three preliminary designs for separate coal liquefaction process schemes. The "Demonstration Plant" design based on processing 10,000 tons per day of coal to produce approximately 25,000 barrels per day (BPD) of liquid fuels using a modified Solvent Refined Coal (SRC) technology is a matter of public record (see OCR R&D Report No. 82 - Interim Report No. 1). The other design reports are being finalized.

The characteristics of the very large coal conversion facilities that we will discuss today represent the results of rapid modification and extrapolation of prior preliminary designs; Parsons was asked by PIB to define characteristics of two coal conversion facilities, each to produce 100,000 BPD of liquids plus significant high Btu gas (SNG). The following sections describe the objectives of our work and projected key characteristics of these facilities. In some respects the information presented here will differ from that published in the June 1, 1974 and July 8, 1974 Synthetic Fuels Task Force Reports.

II. OBJECTIVES

The objectives of our PIB work are summarized in the attached Figure 1. In summary, the objectives encompass rapid planning-type definitions of facility, economic input requirements, and national performance limitations.

To properly assess these objectives, it is helpful to place the size of the facilities in perspective along with the degree of extrapolation from the current experience base in coal conversion plants. The two plants considered in our PIB work required approximately 60,000 and 140,000 tons per day of feed coal. Let's compare these feed rates with two examples of prior industrial coal conversion experience. The Germans, during World War II, operated a number of coal liquefaction plants feeding approximately 600 tons per day of coal per single-line unit; these used the Berguis process. In another case, the SASOL plant now using the Fischer-Tropsch technology feeds approximately 5,400 tons of coal per day. In the U.S., the largest coal liquefaction pilot plant in the public sector has a capacity of approximately 50 tons of coal per day. However, on the positive side, we will see in a following section that the majority of process units in these facilities have been in use on a large commercial scale in the petroleum and petrochemical industries; this experience is fortunately available to us for design of the large coal conversion plants.

III. CHARACTERIZATION OF LIQUID FUEL-PRODUCING FACILITIES

There are several ways that liquid fuels can be produced from coal. These include:

(1) Hydroliquefaction

(2) Indirect Liquefaction (the principal example uses Fischer-Tropsch technology

(3) Pyrolysis.

Because of time limitations, the principal discussion here will center on the procedure to liquefy by hydroliquefaction. Where appropriate, information on the Fischer-Tropsch technology will be included.

IV. MATERIAL FLOWS

The quantities of material flows for the oil/gas modified SRC coal liquefaction facility are shown in the attached Figure 2. As shown, materials and energy inputs to the facility would consist of coal, air, water, and electricity. Approximate input quantities are 60,000 tons per day of clean, washed, high-sulfur coal; 12,000 tons per day of oxygen; approximately 150,000 tons per day of water (equivalent to 110 acre-feet per day) and 300 megawatts of electrical power. Products expected include 100,000 BPD of liquids containing approximately 0.4 weight percent sulfur and approximately 580-million standard cubic feet per day of SNG. Based on use of 3-1/2% by weight of sulfur content of the feed coal, approximately 2,000 tons per day of sulfur would be produced.

A similar materials flow summary for a large Fischer-Tropsch facility is shown on the attached Figure 3. In this case, a design concept was adopted which resulted in production of significantly more SNG. As a result of this fact, plus the lower thermal efficiency of a Fischer-Tropsch type facility, the feed coal would be approximately 140,000 tons per day. In addition to coal input, the facility would require approximately 40 acre-feet per day of water, 49,000 tons per day of oxygen and 900 megawatts of electrical energy. Principal products are 100,000 BPD of liquid with nil sulfur content and approximately 1,700-million standard cubic feet per day of SNG. Sulfur by-product would amount to approximately 4,850 tons per day.

The above information summarizes the large materials flows involved in these complexes. By comparison, the large coal gasification facilities now being planned for the western U.S. would produce approximately 250-million standard cubic feet per day of SNG. Therefore, the coal liquefaction complex described in Figure 2 would have an SNG output 2-1/3 times that of current commercial SNG plant plans whereas the Fischer-Tropsch plant would produce more than 6-1/2 times as much.

V. DESCRIPTION OF FACILITY

The attached Figure 4 shows an artist's conceptual drawing of what a large coal liquefaction plant would look like. This is an adaptation of earlier work for the 10,000-ton-coal-per-day Demonstration Plant design and is included to illustrate the nature of the principal elements of this type of facility.

We estimate that the 100,000-BPD complex would occupy approximately 1,300 acres, or 2 square miles. Additional land would be required for a buffer zone surrounding the plant proper. Because of the quantity of water required, it should be located close to an adequate water source. For comparison purposes, it would use approximately four times as much water as the large gasification plants being planned for construction in the western U.S.

VI. PROCESS CHARACTERISTICS

A summary of the eleven primary process steps involved in a plant to liquefy coal to produce low-sulfur liquid fuels is given in the attached Figure 5. This summary is of particular interest because it shows that six of the process steps have been commercially demonstrated in related mining, petroleum, and petrochemical technology. While there are some modifications required to assure performance in a coal conversion complex, they represent an extension of known technology rather than radical new developments. Those steps peculiar to coal liquefaction and coal-based SNG production development are centered in the five following units:

- Unit 3: Coal liquefaction (dissolving)
- Unit 4: Mineral separation (solids separation)
- Unit 5: Liquids hydrotreating
- Unit 9: Methanation
- Unit 11: Coal/coal residue gasification

Comments on the development or commercial status of each of these steps are given in Figure 5.

VII. SCHEMATIC PROCESS PRESENTATION

The attached Figure 6 schematically depicts how the separate process steps previously listed work together. It also shows the flow of coal and intermediate products through the complex. Since our time is limited, we must refer you to published information for more detail on this subject.

VIII. LOCAL ECONOMY IN INFRASTRUCTURE INTERACTION

For planning purposes, we envision that this type complex would provide direct employment to approximately 2,200 personnel. Employment to staff the mining and transportation activities would be in addition to this. Based on expected economic multipliers for a high-income developed economic area, the process facility would then provide employment for more than 6,000 people. The inference is that the total population center supported by this facility would be of the order of 25,000 plus. The economic multiplier for indirect support employment would be greater than the above in less economically developed areas of the country.

IX. ENVIRONMENTAL FACTORS

Probable major plant effluents leaving this complex are waste solid, waste water, and gaseous streams. Waste solids consist of gasifier slag and coal refuse amounting to about 10,000 tons per day which is returned to the mine for burial. Liquid water waste amounts to about 38,000 tons per day of treated process, cooling tower, and boiler blowdown water. Finally, approximately 120,000 tons per day of various combustion and purified gases are released to the atmosphere. These effluents are judgmental, based on prior analysis of the environmental factors for the 10,000 tons per day Demonstration Plant.[1]

We have recommended that the quantities and compositions of effluents be further confirmed by the results of operation of pilot plant facilities during the course of the next several years.

There is no reason to expect that this type of facility will not meet current environmental standards.

X. APPROXIMATE ECONOMICS

The economic projections that follow are based on judgmental decisions regarding process and equipment improvements expected during the course of the next five years; we originated some of these judgments and others were supplied to us by OCR personnel. We recommend that the development program be so directed to confirm or deny that these projected improvements are realistic. An example would be investigation of the means of speeding up the coal liquefaction rate to increase the production capacity or, saying it another way, requiring significantly less steel to produce a barrel of liquid product.

All economics given are based on mid-1973 dollars.

Based on the parameters used, a judgmental estimate is that the fixed capital investment for a 100,000-barrel per day liquid coal liquefaction facility would cost on the order of $1 billion, mid-1973 basis. The potential gross production cost excluding interest and depreciation allowance is projected to

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[1] O'Hara, J.B. et al., "Environmental Factors in Coal Liquefaction Design," Paper presented at EPA Symposium on Environmental Aspects of Fuel Conversion Technology, May 14, 1974.

be approximately $0.74 per million Btu based on use of $7.25 per ton coal cost. The projected product selling price is $1.22 per million Btu based on a 12% discounted cash flow for a debt/equity ratio of 75/25 and an interest rate of 9%.

In comparison, a Fischer-Tropsch facility with the product capacity earlier described in Figure 3 might have a fixed capital investment requirement of $2 billion, mid-1973 basis. The projected production cost is approximately $0.84 per million Btu. The required selling price, same basis as listed in the preceding paragraph, is $1.37 per million Btu. Additional details describing the economic parameters are listed in the attached Figure 7.

1. DEVELOP RAPID PLANNING-TYPE JUDGMENTAL DEFINITIONS OF CHARACTERISTICS AND APPROXIMATE ECONOMIC INPUT REQUIREMENTS FOR THE FOLLOWING TYPE LIQUID-PRODUCING COAL CONVERSION FACILITIES, EACH TO PRODUCE 100,000 BARRELS PER DAY OF LIQUIDS PLUS SIGNIFICANT SNG:

   A) MODIFIED SRC TECHNOLOGY

   B) FISCHER-TROPSCH TECHNOLOGY

2. DEVELOP RAPID ESTIMATES OF THE ALLOCATION OF RESOURCES REQUIRED TO CONSTRUCT AND OPERATE THESE FACILITIES.

3. DEVELOP RAPID ESTIMATES OF DEVELOPMENT, DESIGN, PROCUREMENT, AND CONSTRUCTION SCHEDULES FOR U.S.A. COMMERCIALIZATION OF THESE TECHNOLOGIES.

4. TO CONSIDER AND DEFINE THE NATIONAL RESTRAINTS WHICH WOULD LIMIT THE ABILITY TO SUCCESSFULLY COMPLETE THESE PROJECTS.

Figure 1 - Statement of Objectives

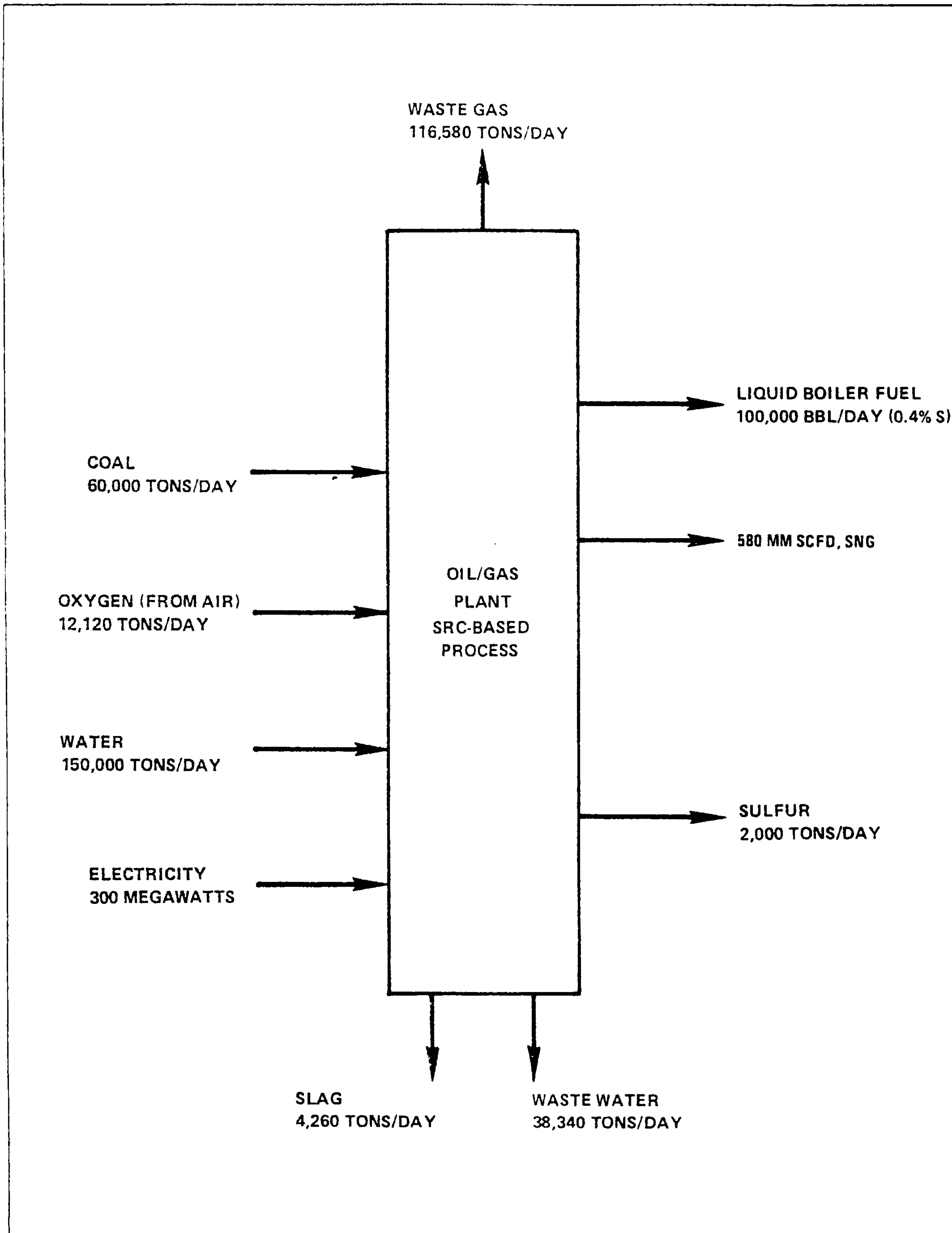


Figure 2 - Overall Material Balance
SRC-Based Process

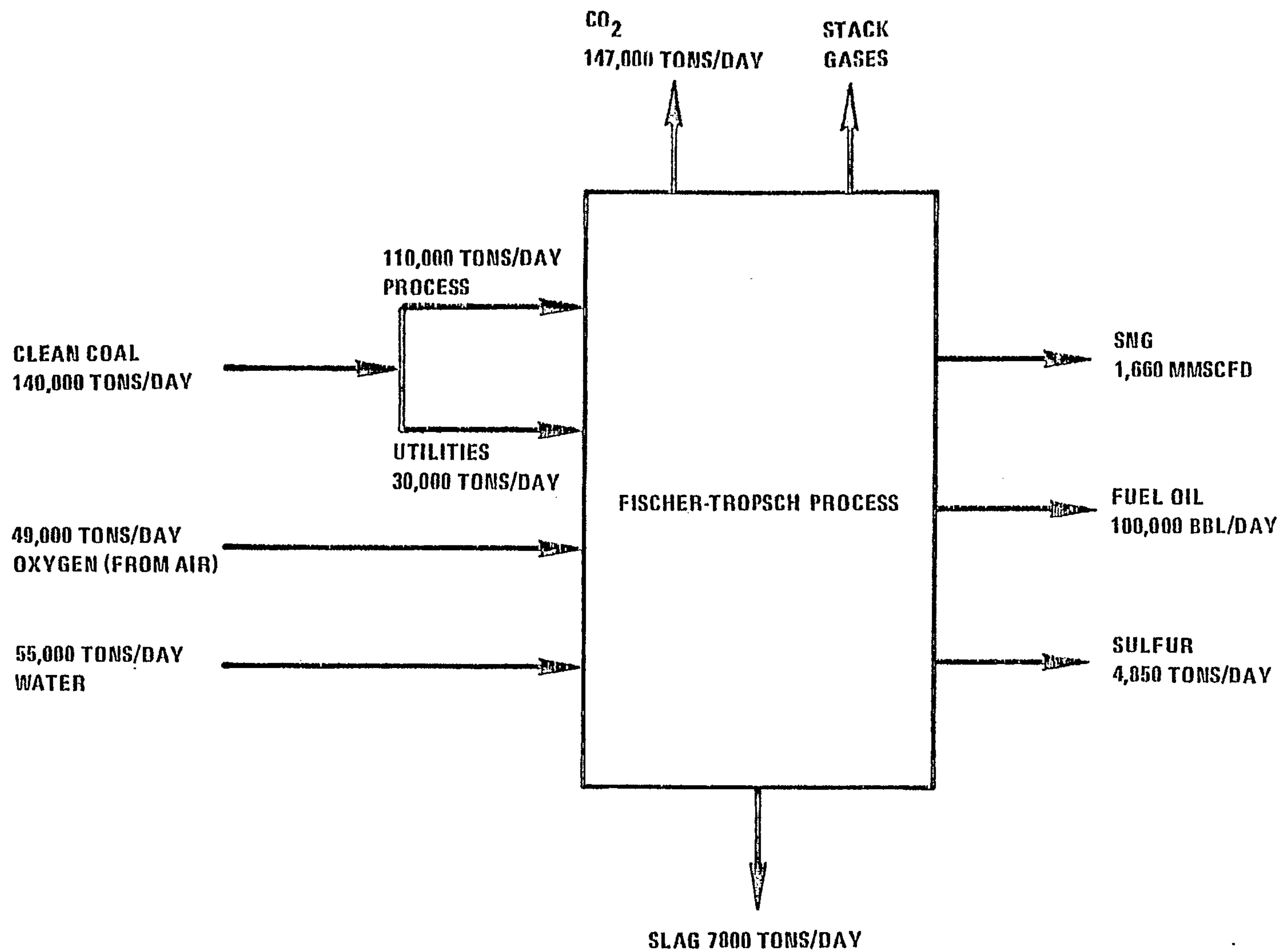


Figure 3 - Overall Material Balance - Fischer-Tropsch Process

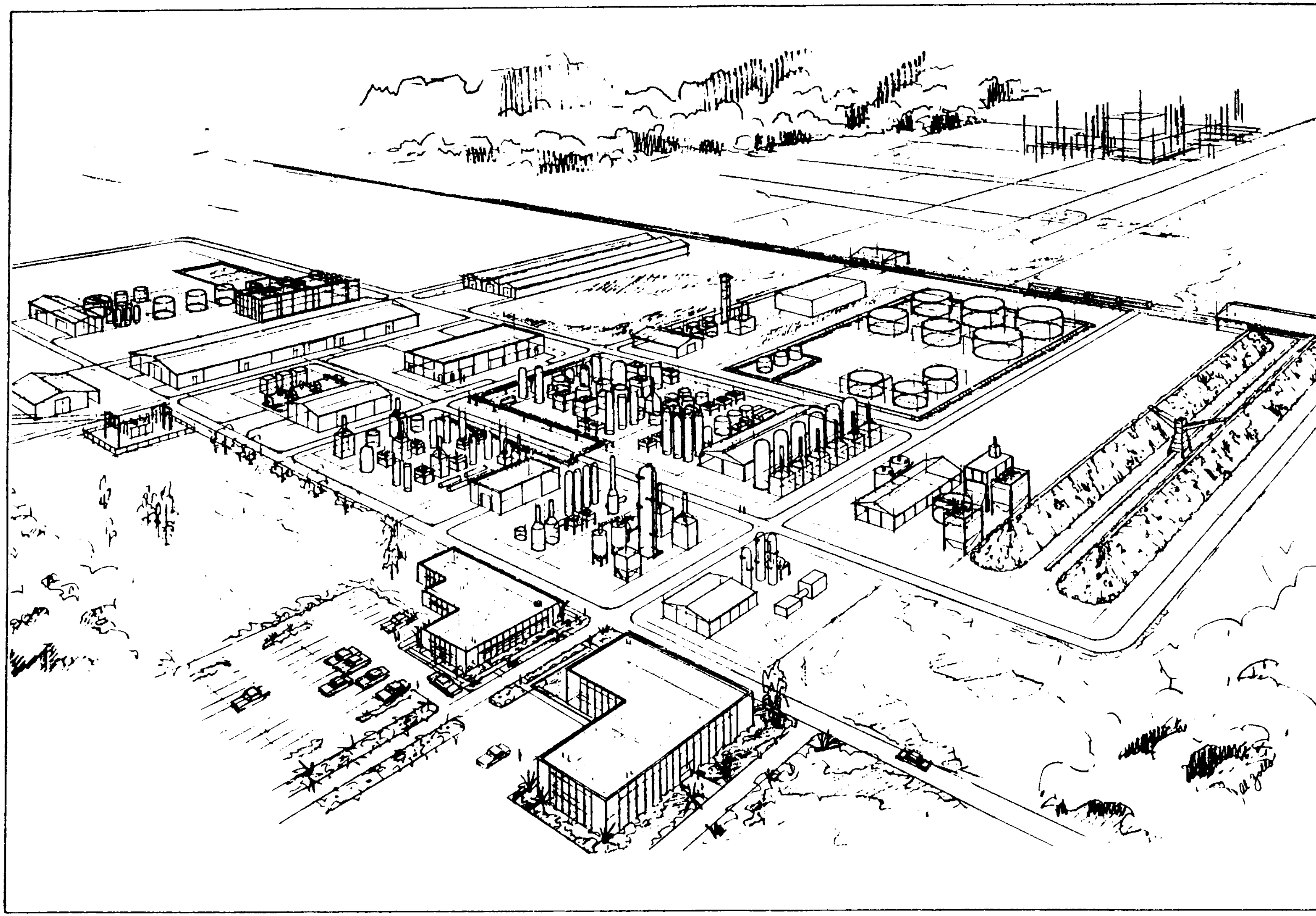


Figure 4 - Artist's Concept of Typical SRC-Based
Oil/Gas Plant

Unit No.	Process Step	Status
1	Mining and Transport	1. Commercial strip mining at present are 6 to 8 million tons/yr operations. Multiple mines will be required for Oil/Gas plant.
2	Coal Preparation	2. Commercial operations presently operate at 6 to 8 million tons/yr. No major design or operational problems are expected.
3	Coal Liquefaction	3. This is in development stage. SRC pilot plants at 6 and 50 tons/day will be operating this year. Only industrial-scale operation was the Berguis process operated in Germany during World War II.
4.	Mineral Separation (Solids Removal)	4. This is in development stage. Present pilot plant and bench scale work indicates additional test work is required to define most economic process method for this process step.
5.	Liquids Hydrogenation	5. This still has some development left to improve operations. Additional development work is required on synthetic coal-derived liquids to augment present commercial petroleum operations. COED pilot plant has operated satisfactorily to date.
6.	Acid Gas Removal	6. Commercial plants are presently in operation capable of processing about 100 MM SCFD. Multi-train units would be utilized for Oil/Gas plants.
7.	Shift Conversion	7. Commercial natural gas-based plants are presently in operation. Multi-train units of 50-100 MM SCFD would be used for Oil/Gas plants.

Figure 5 - Summary of Process Steps

Unit No.	Process Step		Status
8.	CO_2 Removal	8.	Commercial gas treating plants are in operation. Multi train units of 50-100 MM SCFD would be used for Oil/Gas plants.
9.	Methanation	9.	Technology on a semi-&/or commercial-scale has not yet been proven. Additional demonstrator methanator development work is required. Lurgi now claims commercial experiences and Westfield, Scotland claims producing SNG in commercial quantities.
10.	Sulfur Recovery	10.	Sulfur recovery units of commercial size have been in operation successfully. Tail gas final gas cleaning would be multi-train units.
11.	Gasification (Coal/Liquid residue)	11.	In development stage. Only the Lurgi and Koppers-Totzek gasifiers are commercially (low pressure) proven units. Additional development work is required on high-pressure (500-1500 psi) gasifier before commercial plant design is a reality.

Figure 5 - Summary of Process Steps

Page 2 of 2 pages.

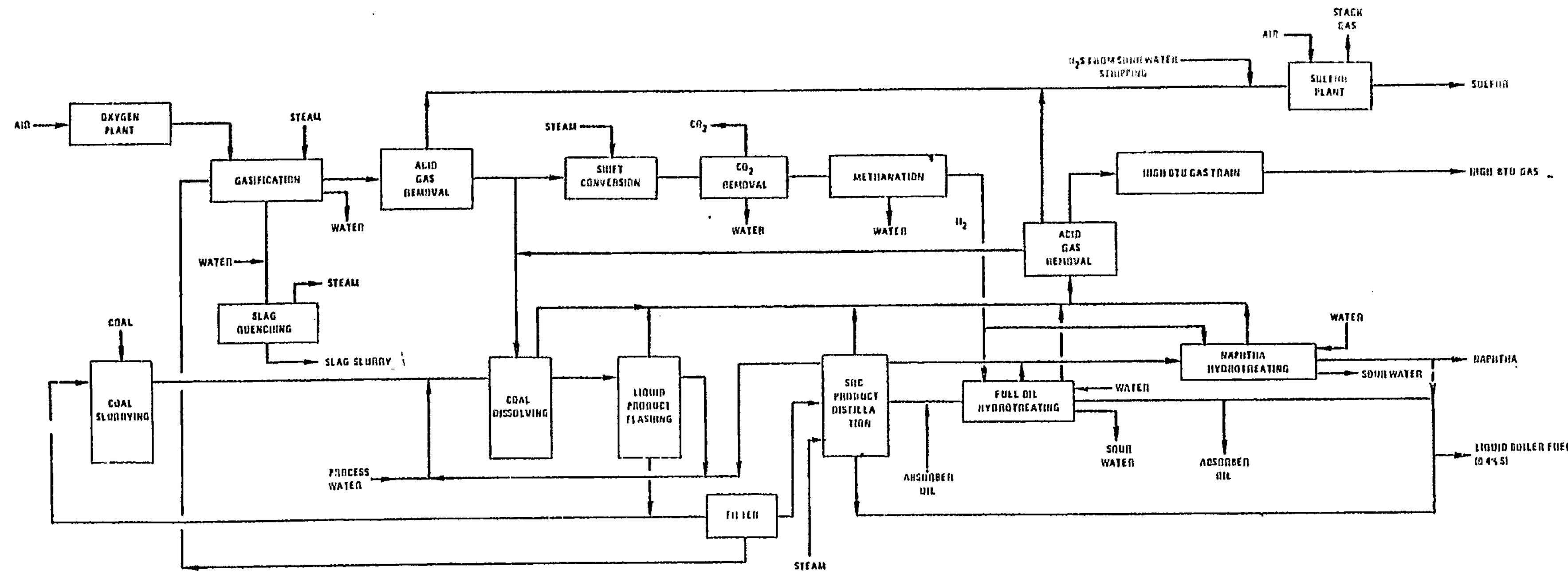


Figure 6 - SRC-Based Oil/Gas Plant Process
Block Flow Diagram

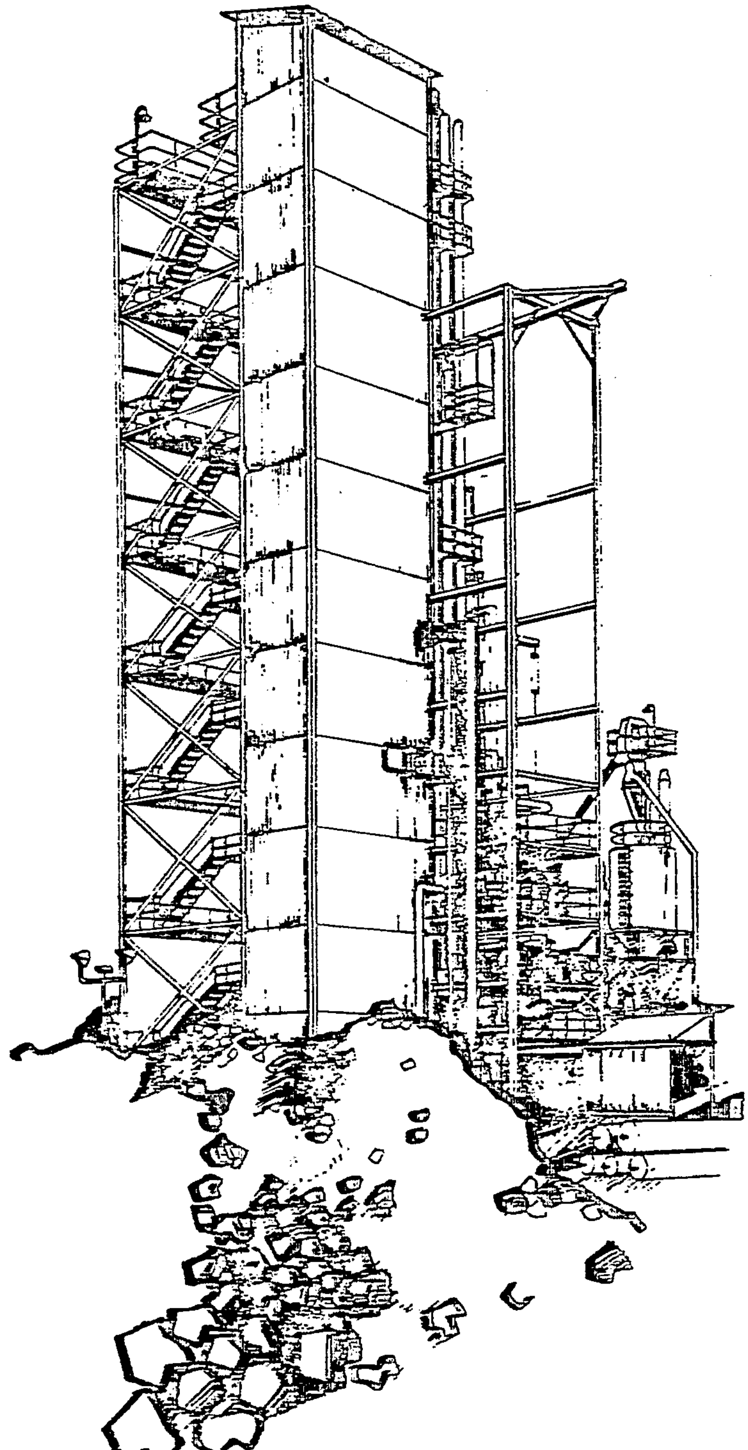
ECONOMIC PARAMETERS

1. INTEREST RATE = 9%
2. COMMITMENT FEE ON CONSTRUCTION LOAN = 0.5%
3. DEBT/EQUITY RATIO = 75/25
4. PROJECT LIFE = 20 YEARS
5. DEPRECIATION SCHEDULE; 20 YEARS, STRAIGHT LINE (TO CONFORM TO PIB STANDARD)
6. DESIGN/CONSTRUCTION SCHEDULE = 5 YEARS
7. WORKING CAPITAL:
   a) Oil/gas SRC based = $100 MM
   b) Fischer Tropsch = $200 MM
8. STARTUP COSTS:
   a) Oil/gas SRC based = $60 MM
   b) Fischer-Tropsch = $120 MM
9. 330 STREAM DAYS PER CALENDAR YEAR
10. COAL PRICE = $7.25/TON, DELIVERED

Figure 7 - Economic Parameters

COLLECTED WORK NO. 5

CLEAN FUELS FROM COAL SYMPOSIUM II PAPERS



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COMMERCIAL COAL CONVERSION PLANT DESIGN: TRANSLATION FROM PILOT TO COMMERCIAL-SCALE PLANTS

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ABSTRACT

The United States coal conversion development program is approaching a major crossroads. Both public and private sector authorities have supported the objective of beginning to move coal conversion processes into large-scale plants to provide a basis for objective decisions regarding the true potential for supplying a significant portion of the future U.S. energy needs. Affirmative action would mean an accelerated development schedule including design, construction, and operation of multiple demonstration and/or commercial-scale plants. When this occurs, an integral part of the successful program will be translation of pilot plant results into large-scale plant designs. The Ralph M. Parsons Company has been involved in doing just that in their program to assist ERDA in the development of commercial coal conversion plants. This paper summarizes key elements of translation and scale-up programs.

Fundamentals of translating pilot plant experience to commercial plant design are discussed. Factors considered include early definition of commercial plant objectives, basic data requirements, and scale-up criteria. Pilot plant data/information supply and analysis require cooperation between client, process developer, and plant designer. The interactions between the process development and the plant design schedules are discussed. Procedures for analysis of the pilot plant results and development of commercial plant design basis are described. An illustration of the application of a translation/scale-up program is given.

These procedures are useful for preliminary and conceptual designs of commercial coal conversion plants. The most important report on the subject will follow successful design, construction, and operation of demonstration and commercial-scale plants.

COMMERCIAL COAL CONVERSION PLANT DESIGN:
TRANSLATION FROM PILOT TO COMMERCIAL-SCALE PLANTS

I. INTRODUCTION

At present the U.S. coal conversion program is approaching a major crossroads which will profoundly influence our topic of commerical coal conversion plant design.

Both President Ford, in his January State of the Union address, and Dr. Robert C. Seamans, Jr., speaking as head of the Energy Research and Development Administration on March 21, outlined a basic national objective: to develop the ability to produce, within our own borders, the equivalent of one million barrels per day of oil equivalent from coal by 1985; the products would consist primarily of oil and substitute natural gas (SNG).

Previously, on March 3, a group of key private sector personnel involved in coal conversion development were invited by the U.S. Senate Committee on Interior and Insular Affairs to present their views. The consensus among the group was to recommend that the United States should now proceed with a program to build and operate multiple large coal-conversion plants in order to further explore the capabilities, reliability, and economics of current U.S. coal conversion technology as well as begin to supply a significant amount of synthetic fuels.

If we are to achieve our goal of one million barrels per day equivalent by 1985, prompt funding and activation of such a development program are essential. Depending upon the number of plants to be built, and the priority assigned to the program, probable program costs range from $2 to $5 billion.

This crossroads is therefore upon us now. On the one hand, the route recommended means accelerated development of existing processes into multiple demonstration and possibly commercial-scale plants and operations, as described to the U.S. Senate. On the other hand, the alternative path would be continued development including pilot plant operations but lower priority performance testing and plant economics investigation for large-scale plants.

A number of processes have now been tested in pilot plants of a size sufficient for design of demonstration-scale plants. In the event of a national emergency, pilot plant results could serve as the basis for commercial plant design. Incentives for proceeding aggressively with large-scale coal conversion plant projects include that the U.S. has recently experienced an oil embargo by the major exporting nations, world oil prices have increased by a factor of approximately four with the long-term trend still up, and consumption has declined only moderately. It seems inevitable that the U.S. will require additional energy sources in the near future to maintain industrial and economic vitality--with coal conversion a major option for increasing our oil and gas supply from indigenous resources.

To summarize, both public and private sector authorities have now supported the objective of beginning to move coal conversion processes into larger scale plants to provide a basis for objective decisions regarding their true potential for supplying a significant portion of future U.S. energy needs.

Turning to the specific topic of this paper, an integral part of a successful demonstration and commercial plant program is a means of translating pilot plant results to large-scale plant designs with the best chances of moving smoothly into reliable and economic operation. The Ralph M. Parsons Company has for a number of years been involved in the development and improvement of procedures for translating coal-conversion pilot plant operating data into larger scale plant designs. This paper will summarize many key elements of translation and scale-up programs and, in addition, seek to develop a basis for further objective exchanges of views on procedures for successful achievement of the U.S. coal-conversion commercialization program.

Translation from pilot plant to commercial plant for a complex technology such as coal conversion is a broad and intricate subject. Within time available for this presentation, we have chosen to present a summary of key criteria and information items required, suggested methods of data analysis and scale-up use, and an example of application of scale-up techniques. Emphasis will be placed on items that characterize coal conversion technology. Analogies to related process technologies such as oil refineries, petrochemical plants, steel industry processing, and gas processing facilities will be presented as appropriate.

A last introductory comment: the true test of skill in scale-up practice is the performance of the large-scale plant. Until that is done, performance can't be judged. We look forward to reporting again after large plants have been designed, built, and operated.

II. PARSONS ROLE IN THE COAL CONVERSION DEVELOPMENT PROGRAM

The Ralph M. Parsons Company is actively assisting ERDA in development of commercial plants for conversion of coal to clean fuels. Two major activities are involved in Parsons participation:

(1) Parsons supplies Preliminary Design Services in which it develops preliminary/conceptual design and estimated economics for commercial plants. An example of a design is illustrated in Figure 1, which shows an artist's sketch of a plant to convert approximately 10,000 tons per day of high-sulfur coal to about 25,000 barrels per day of low-sulfur liquids consisting of fuel oil and naphtha.

(2) Parsons supplies services to ERDA as a Technical Evaluation Contractor for the clean liquid and/or solids coal conversion development program. In this role, Parsons monitors coal liquefaction pilot plants and provides professional services to assist ERDA in advancing these programs.

To summarize, Parsons is active in the experimental development program and in the preliminary design of commercial facilities plus development of economic estimates for these plants. The results of the work to date have been published in a number of prior reports and technical publications. (References 1 through 6.)

III. FUNDAMENTALS: TRANSLATION OF PILOT PLANT EXPERIENCE TO COMMERCIAL PLANT DESIGN

A. Commercial Plant Objectives

The commercial plant objectives should be defined early in the development-plant design program to provide guidance for scale-up criteria and design. Examples of factors to be considered in setting objectives are shown in Table 1.

A factor that affects selection of scale-up criteria and subsequent plant design is the interaction between plant capacity, required reliability, and economic goals. A distinction can be made between large synthetic fuels plants which are close-coupled to a base load utility with minimum intermediate storage capacity, vis-a-vis a plant designed to be a competitive or lowest cost synfuels producer with large product storage and efficient large-volume product distribution capability.

Still another possibility is a size-reliability-economics combination chosen to meet national security objectives.

Other factors to be considered in setting scale-up and design criteria include flexibility provisions for product mix and their specifications, location, labor pool factors, and environmental restraints.

In the usual case, the final definition of commercial plant objectives represents a tradeoff between the factors. We therefore suggest that objectives be developed as early as possible to provide a clear understanding of what is expected from the plant. Subsequent decisions can be made to provide the best features to achieve project objectives.

B. Basic Data Requirements

The prime consideration here is that pilot-plant operation should provide a detailed basic understanding of the chemical, mechanical, metallurgical, and control engineering factors required for design and operation of the coal conversion facility. Once basic process and equipment behavior patterns are known, then process scale-up techniques and equipment selection procedures can be applied with confidence. A description of required basics will be presented in this section of the paper.

Also of key importance is a definition of the accuracy and precision of the pilot plant data. The numerical value of a design factor--for example, yield data--can be mathematically defined by stating the average value for the item plus a standard deviation. As used here, precision is directly related to the standard deviation measurement. Availability of this standard deviation is important because it provides a basis for a design decision: the range of operating flexibility that must be built into the plant design. This decision in turn affects fixed capital investment and operating costs. Accuracy of design points can often be determined by internal checks of data such as material, energy, or elemental balances.

Further details on the points described above follow.

1. Accuracy and Precision of Data. This is discussed first because it affects all items in pilot plant data reporting and their use in

commercial-scale plant design. We all recognize that during the early stages of pilot plant operation, a prime objective is to prove that the process and the installed equipment are operable and that usable data plus product can be produced. Achievement of this objective, and development of confidence in pilot plant operations and reliability often require considerable time, effort, and expense. Once that goal has been achieved, the pilot plant may determine processing characteristics of a number of types of coals and the effects of various process equipment and process variations on performance and efficiencies.

We suggest that accuracy and reproducibility of the data be determined early in the pilot plant program. When preferred conditions for operation of the process have been defined, multiple runs under those conditions are desirable. The results obtained permit calculation of standard deviation as a measure of precision.

This information is valuable for the design of larger scale plants using similar conditions, and is also of significant importance in process preference or optimization studies. In these cases, it is possible that design criteria and objectives for the full-scale plant differ from those understood to exist during the course of pilot plant design and operations. We will discuss in more detail later the incentives for good communications between the client, process development contractor, and the plant designer in order to determine ultimate plant design criteria as early as possible in the program.

Once accuracy and precision data are available, tests of significance can be applied to results of comparisons of process alternatives. In this way we obtain improved probability that the preferred process selection is made by quantitative, objective means. Economic incentives for using the best alternative in the design of large, high-capital-investment coal conversion plants are signficant.

2. Analytical and Control Accuracy. Early determination of the accuracy and precision of analytical measurements as well as measurement and control instruments is important. By this means results of the process variable studies can be compared using tests of significance to determine whether in fact a measurable change or improvement can be reliably expected to have occurred. These results provide guidance regarding probabilities of correct design decisions based on a limited number of measurements; they influence all data procurement and analysis as well as plant design activities including scale-up.

3. Materials and Stream Properties. Availability of complete and accurate chemical composition and physical and thermal properties for all raw materials, products, and intermediate streams is a necessity for efficient commercial-scale plant design. Accumulation of complete data on these subjects should have high priority during the small-scale and pilot plant development program. Examples of required data are shown in Table 2.

We suggest that the accumulation of a Design Data Book containing the above information, plus additional data, should also have high priority in the pilot plant and supporting experimental program.

4. Basic Chemical Engineering. The fourth category consists of elements which have been grouped under the heading of Basic Chemical Engineering. Examples of items are listed in Table 3.

The availability of accurate basic chemical engineering data as illustrated in Figure 4 provides a sound foundation for the application of translation and scale-up techniques.

5. Process Performance. We recommend that an experimental design to determine the effects of process variables on process performance be developed early in the pilot plant program. One of several approaches would use statistical tools; this could apply a factorial replicate of a factorial experiment. The data generated from this program would lend themselves to effective data correlation procedures as well as minimizing the amount of experimental work required to obtain the correlations. The data also permit rapid determination of tests of significance as guidance for decisions regarding selection of preferred or optimum operating conditions.

We also recommend that the development of procedures for accurate on-line determination of instantaneous material and heat balances be emphasized in design and operation of the pilot plant. Development of these methods and data requires considerable attention to detail, painstaking work, and ingenuity in instrumentation use. Once it is achieved, however, the pace of obtaining meaningful design data accelerates markedly. Results of the effect of process variables on process and plant performance can then be scouted by perturbation and EVOP techniques leading to increased knowledge of expected results and sensitivities as conditions change in the commercial plant.

Process performance data supply a key basis for subsequent scale-up and design work. Samples of data requirements are given in Table 4.

6. Equipment Performance. The preferred situation is to test, in the pilot plant, types of reactors and equipment best suited for full-scale commercial plant operation. In some cases this may not be practical because of lack of availability of proper equipment in time for the pilot plant design/construction program. In other cases, information may be obtained during the course of pilot plant operations showing that equipment different from that under test is best suited for commercial scale operations. If, however, pilot plant operation provides a sound theoretical basis for scale-up, then use of alternate sizes and types of equipment for large plants can often be effectively accomplished using the pilot plant data--or using pilot plant data in conjunction with a coordinated equipment test program in cooperation with equipment suppliers.

We suggest that pilot plant operations provide the type of information described in Table 5 as a basis for scale-up and design work.

Pilot plant operation and experience gained in methods of correlating maximum pilot plant performance and capacity should lead to equipment recommendations. Availability of complete pilot plant specifications is important, since they should be reviewed often prior to placing orders for commercial-scale equipment. If there are reasons for limiting maximum sizes of equipment that were originally determined during pilot plant development, this should also be considered.

The mechanical performance history of equipment during pilot plant operations represents another important input to commercial plant design. This includes recording maintenance history and reliability (on-stream time) for the major units, particularly for the period after start-up and shakedown. During this period hopefully there is reliable and continuing operation of the pilot plant. If there are complicating factors caused by extremes in operating conditions during the study of process variables/process performance, it is helpful if that information is reported.

7. Materials of Construction. Records and recommendations are important. In this respect, we recommend that a general corrosion testing program be an integral part of the design and operation of the pilot plant. Wherever practical, corrosion coupons should be inserted to permit selection of the least-cost reliable material selection; use of test spool pieces of various candidate materials of construction can make valuable contributions to this part of the program.

8. Safety and Hygiene. Information, data, and recommendations from the pilot plant regarding these facets of design and operations requirements are important. Examples of types of information required are shown in Table 6.

We recommend that a safety and hygiene report be prepared based on pilot plant experience and prior to large-scale plant design. One factor now under study is preferred personnel protection from potential carcinogenic and dermatitus-inducing characteristics of coal-based liquid products. We also recommend preparation of the equivalent of a Chemical Safety Data Sheet for materials and mixtures specific to the coal conversion processes.

9. Environmental Factors. Pilot plant operations should define composition and quantities of process effluent gaseous, liquid, and solid streams. In many cases, this will require careful measurement of compounds present in small or trace quantities. Examples include mercury and toxic sulfur compounds. Pilot plant operations should also provide results of test treatments of effluent streams that are peculiar to coal conversion processes and not available from experience gained in other process industries.

Examples of environmental factor data requirements are given in Table 7.

We submit that it is important that definition of environmental factors be developed early in the pilot plant program to permit time for analysis and design of the commercial plants in such a way as to generate public confidence that the plants are environmentally acceptable, to prepare the necessary documents, and to obtain licenses to construct the facilities.

These steps are inherently time-consuming. They should be programmed so that completion is consistent with the plant design/construction schedule. This will be most critical for the first large plants to be constructed.

10. Summary. Availability of the data described in Section III-B-1 through -9 provides a sound basis for translation of the pilot plant results to full commercial scale. We recommend that development of all these data be given high priority in design and operation of the pilot plant.

It will be an unusual case, however, where all of the data we have listed can, in fact, be obtained with the desired degree of completeness and reliability, and in time, for use in initial large-scale plant design. Realistically, therefore, it is necessary to agree on and emphasize priority items during a pilot plant development program. For finalization of scale-up for these cases where data are lacking, use of related scale-up experience from other industries as well as correlations and extrapolations of other data sources would be pressed into service.

For cases where key data are lacking, engineering judgment based on related industries would be applied. The net result is a compromise in projected reliability during the early days of commercial plant operation, and recognition that additional changes can be expected before the plant reliability is acceptable. The alternative is increased capital investment caused by built-in equipment redundancy and/or oversizing some plant sections.

C. Criteria for Scale-up

A first step in scaling up any process or equipment unit is to define criteria to be used for scale-up. Criteria may be performance-based or economics-based. They can include assessment of tradeoffs such as conversion vis-à-vis ultimate yield. An example of scale-up criteria for a hydroliquefaction dissolver vessel is shown in Table 8. Illustrative scale-up procedures will be discussed later in this paper.

Criteria for scale-up should be specific. In this respect, please recognize that a representative coal conversion complex can contain as many as 70 separate equipment categories. A number of these are illustrated in Table 9.

One factor that is a prerequisite for scale-up criteria is the time frame for design, construction, and operation of the facility. Where equipment selection and purchase is planned for the immediate future and for tight delivery schedule, the pressure is to accept, with minor modifications, equipment with performance already demonstrated on a commercial-scale in the same application, or one closely related to it.

Conversely, where specific large plants are planned for completion well in the future, scale-up criteria and schedule may incorporate equipment development and test work prior to finalization of design.

An example might be in the field of coal gasification. For imminent purchase of the gasifier, shop fabrication and testing of the gasifiers and other vessels would be prudent. However, a subprogram is now under way to evaluate incentives for using large field-fabricated gasifiers and supporting equipment. In this case, a careful analysis of scale-up factors for gasifiers in the range of 20-25 feet in diameter and pressures to 1,000 pounds per square inch is justified; it is also timely. To reduce this concept to practice, the design, fabrication, erection, testing, reliability, and economic factors must all be carefully evaluated and sufficient lead time allowed to develop and implement a program to achieve the goals. Included in this evaluation should be the installation, operating, and maintenance cost of ancillary equipment items such as the multiple pumps, heat exchangers, and knockout drums. The multiplication of pipe runs, control instrumentation, and electrical facilities must also be evaluated. Startup of such a facility in 1985 could lead to one conclusion regarding maximum gasifier size, whereas required startup in 1979-80 could lead to an entirely different conclusion.

The reliability-economics tradeoff is a key criteria decision area in the field at this time. High reliability demands may dictate the use of multiple small reactors and vessels; where the objective is to score an economic breakthrough and become the lowest cost producer, larger reactors and innovative design approaches would be used. Both approaches have been used often in process industries history.

IV. DATA/INFORMATIONAL INPUTS FROM PILOT PLANT OPERATIONS

A. Developer/Designer Cooperation

Program effectiveness is aided greatly by close cooperation and communication between the process developer and the plant designer. A primary goal in this relationship is open discussion and general agreement on the objectives and configuration of the commercial plants to be built. Agreement on the most critical factors to be determined during the course of the development program will ensure that the project is technically and economically successful.

We recommend that the selection of development program priorities be guided by economic analysis results. An example might be the economic incentive for determining the purity of hydrogen to be used for the hydroliquefaction reaction. The incentive would be estimated by comparison of use of, say, 96% hydrogen purity vis-à-vis a synthesis gas containing about 40 vol % hydrogen and 45 vol % carbon monoxide.

The comparison of these two alternative cases in a hydroliquefaction plant should recognize that the result affects technical and economic factors in a number of plant sections, including gas generation, reaction, gas recycle system and product handling and composition. Definition of the preferred route for a given application can best be done by looking at the total system for the two alternative cases and developing preliminary economics including differences in fixed capital investment and operating cost. If there are differences in product characteristics, these should also be included.

Parsons is involved in this type of economic tradeoff evaluation for a number of cases, including the illustration just mentioned. We feel that it has the potential for providing a firm basis for decision and the resulting estimated economic incentive can provide a basis for setting priorities for the development program, including pilot plant operations. This type of comparison must be done carefully and objectively to be sure that indicated differences between the alternatives are, in fact, significant when considered against the background of the quantity and quality of the data used as well as the procedures used to develop the economic comparison.

B. Data/Information Supply Requirements

The data/information requirements were described in detail in an earlier section of this paper. This "shopping list," or a modification of it, can serve as a basis for the development and plant design contractors to work together in developing a design basis that best satisfies the plant design objectives.

Where there are voids in the required data, best judgment, interpolation, extrapolation, or other techniques must be used to fill those voids. The resulting plant design scale-up will pay some price for missing data in one or more of the factors of capital investment, operating costs, reliability, or product characteristics.

C. Data/Information Supply Priorities

The project schedule and the results of preliminary studies of economic incentive implications of design alternatives will suggest priorities required for a timely and successful scale-up. We suggest that the pilot plant program emphasize studies with the greatest economic impact on the commercial plants, and also, the definition of factors related to long-lead items in those cases where prompt movement of the technology to larger scale plants is dictated.

V. DATA/INFORMATION ANALYSIS

Pilot plant and supporting data are reviewed and analyzed to provide the best correlations for use in translation and scale-up. Of prime importance is the correlation of process performance with controllable process variables, and how well the data correlate. Essentially all techniques are applied to this effort, including multiple correlation and regression. The quality of the correlation, the manner with which it is used in the plant design, the plant objectives (see Table 1), and feedback from past design/operation projects affect the design tolerances selected for the separate plant units.

VI. TRANSLATION FROM PILOT PLANT TO COMMERCIAL-SCALE DESIGN

The design of the commercial-scale plant incorporates inputs and procedures described in the preceding sections of this paper. It represents the end product of a lengthy and intensive effort. The translation can best be discussed using an illustrative example.

A dissolver in a hydroliquefaction process, such as the solvent refined coal (SRC) process, has been chosen for the illustration. Key design criteria have been described earlier in Table 8. The illustration will be based on a 10-foot-diameter vessel although larger units are possible and are being designed.

For the case illustrated, data are available from pilot plant and smaller scale Process Development Unit (PDU) work. The experimental work used relatively simple reaction vessels without internals.

Example data for PDU and pilot plant dissolver operation are shown in Table 10. Measured as well as calculated capacity and performance parameters are given. The products from the dissolver in both cases contained less than 10% undissolved coal and are considered satisfactory

Further analysis of PDU and pilot plant experience has led to the following current conclusions regarding the probable mechanism and general direction of effects of variables during the hydroliquefaction reaction which occurs in the dissolver:

Gas Contact Time:

- Not considered a controlling factor.
- Important factor--adequate mass transfer to maintain required hydrogen concentration in liquid phase.

Hydrogen Concentration:

- Maximum hydrogen concentrations in the liquid.
- Design to assure efficient mass transfer.

Solids Residence Time:

- Evidence indicates that conversion to a "nonsolid" is rapid and that the bulk of the required retention time is utilized to depolymerize the "nonsolid."

Liquid Residence Time:

- Adequate reaction/residence time required to effect conversion.

Inactive Zones:

- Must not occur; would lead to "coke" formation or hot spots.
- Gas, liquid, and solid flows should be uniformly maintained.

Flow Distributors:

- PDU and pilot plant units did not use internals.
- Use flow distributors in large plant dissolvers.
- Distributor design should provide wide latitude of gas and liquid traffic and still produce good liquid and gas distribution.
- Distributor design should be simple, easy to fabricate, and easy to remove. It should not use packed joints.

Feel Coal Particle Size:

- PDU and pilot plant experience was with fine ground coal, minus 70 mesh.
- Now judged that minus 1/8-inch coal is satisfactory for large plant use.

Parameters of a large-scale dissolver design are illustrated in Table 11; for reference, PDU and pilot plant data are repeated. Here we see that multiple dissolver vessels would be used; each vessel would be approximately 70 feet in length and the diameter would be 10 feet. The wall thickness would be approximately 7.5 inches based on use of ASME Division II design code.

The vessel design uses a conventional head. One distributor plate is located at the bottom tangent line of the vessel and three more are located at 17-foot intervals counting from the bottom tangent line. This should assure uniform distribution throughout the vessel height.

VII. SUMMARY AND CONCLUSIONS

In summary, effective translation of coal conversion processes from pilot plant to commercial plant design requires continuing and effective communications between client, process developer, and plant designer. Early agreement on commercial plant objectives and schedules, scale-up criteria, and data procurement priorities is important. Decisions regarding data development priorities should be guided by preliminary economic analyses leading to a quantitative basis for these decisions.

Design of coal conversion plants will require translation and scale-up of a large number of equipment and reactor types. An example of a scale-up effort for a preliminary/conceptual design illustrates one set of procedures that can be used.

The important report on this subject will follow the successful design, construction, and operation of demonstration and commercial-scale plants.

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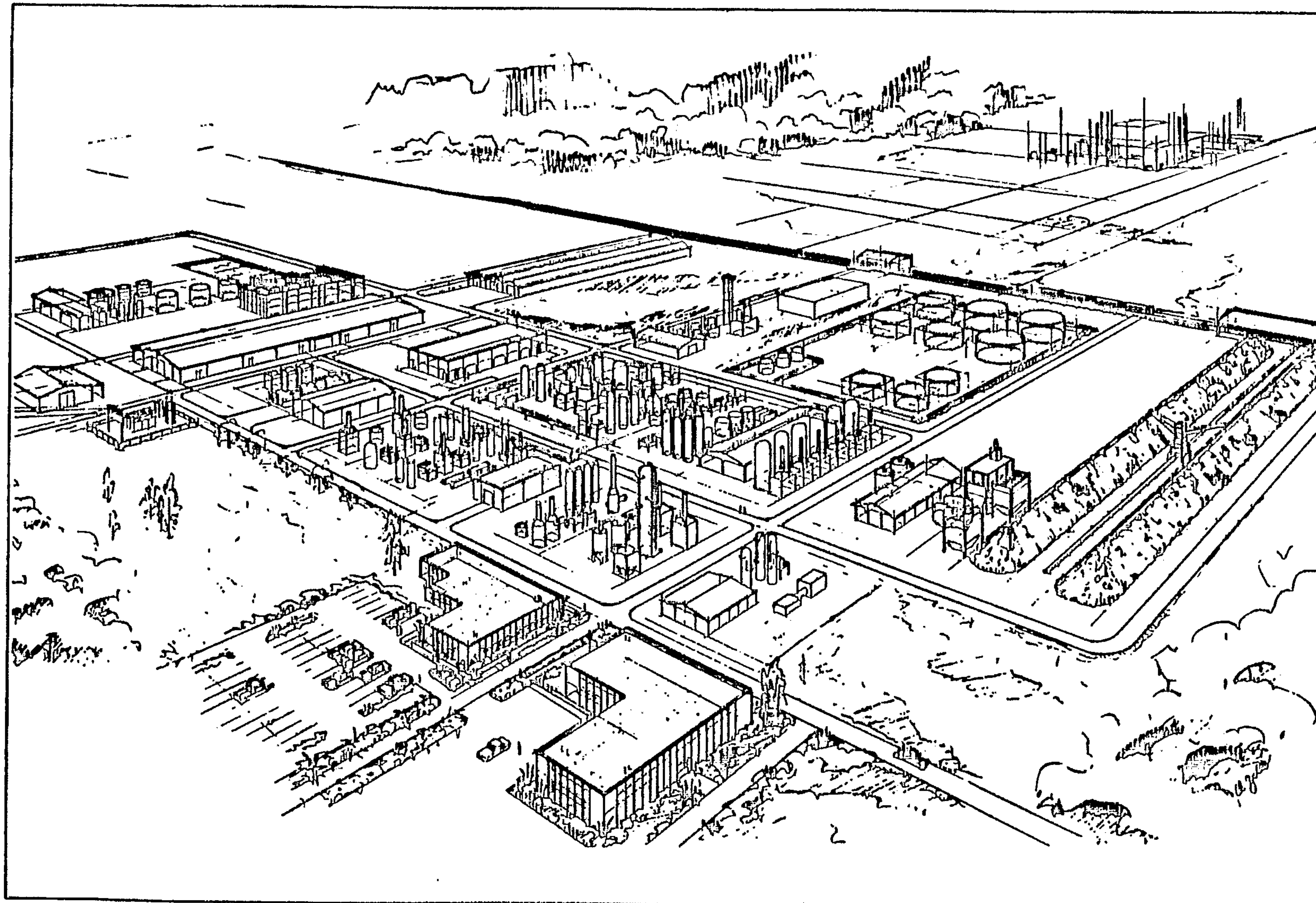

FIGURE 1 - COAL CONVERSION PLANT ARTIST'S SKETCH

Table 1 - Examples of Factors to be Included in Definition of Commercial Plant Objectives

1. Capacity
2. Reliability
3. Economic Goal
4. Product
    - (a) Specifications
    - (b) Product Slate Flexibility
5. Location Factors
    - (a) Construction Labor Availability, Productivity
    - (b) Operations Labor Pool
    - (c) Environmental Factors
    - (d) Water Supply
6. Raw Material
    - (a) Availability
    - (b) Characteristics
    - (c) Logistics
7. Product Storage Capacity
8. Plant Logistics
    - (a) Raw Material Supply
    - (b) Product Distribution

Table 2 - Example Materials and Stream Properties

1. Compositions
(a) Chemical
(b) Elemental
2. Physical Properties; Components and Streams
(a) Viscosities
(b) Densities
3. Thermal Properties
(a) Thermal Conductivities
(b) Specific Heats
(c) Heats of Reaction
(d) Heats Effects for Phase Changes
4. Phase Equilibrium

Table 3 - Basic Chemical Engineering Factors

1. Reaction Kinetics
2. Thermodynamics
3. Fluid Regimes
(a) Fluid Flow
4. Mass Transfer
5. Physical Equilibrium Data
(a) Vapor-Liquid
(b) Liquid-Solid
(c) Multiphase
6. Catalyst Performance
(a) Activity
(1) Poisons
(b) Physical Strength
(c) Economic Life

Table 4 - Examples of Process Performance Data Requirements

1. Material Balance
   (a) Minimum Expected Physical Losses of Intermediate or Recycle Streams
   (b) Dependency on Production Capacity
2. Energy Balance
3. Elemental Balance
4. Chemical Yields
   (a) As a Function of Raw Materials Composition and Process Variables
5. Product Separation, Recovery, and Purification
   (a) Procedures
   (b) Efficiencies
6. Product Compositions
   (a) As a Function of Raw Materials Composition and Process Variables

Table 5 - Examples of Equipment Performance Information From Pilot Plant Operations

1. Detailed Equipment Specifications
2. Equipment Performance History
   (a) Process Performance
   (b) Mechanical Performance
      (1) Maintenance History
      (2) Reliability: On-Stream Time
   (c) Materials of Construction
      (1) Corrosion/Erosion Rate
      (2) Special Fabrication Requirements

Table 6 - Examples of Safety and Hygiene Data Requirements

1. Explosive Ranges for Process Mixtures
2. Flash Points for Components and Process Mixtures
3. Analysis of All Streams for Presence, Identification, and Quantity of Hazardous Materials
4. Allowable Maximum Concentrations for Personnel Exposure
5. Recommended Treatment for Exposures
6. Recommended Personnel Safety Equipment, Treatment Facilities, and Protective Clothing
7. Definition of Special Safety Design and Maintenance Features for Equipment
8. Recommended Safe Startup and Shutdown Procedures

Table 7 - Examples of Environmental Data Requirements

1. Physical Characteristics, Quantities and Compositions of Process Effluent Streams, Including Trace Elements
(a) Gaseous
(1) Odor
(2) Particulate Sizes
(3) Temperature
(b) Liquid
(1) Color
(c) Solid
(1) Leachate Composition
(2) Permeability
(3) Erodability
(4) Texture
2. Allowable Maximum Concentrations in Effluents for Constitutents Specific to Coal Conversion
3. Recommended Modes of Treatment of Effluent Streams and Test Results from Treatment of Streams Specific to the Coal Conversion Process(es)

Table 8 - Example of Scale-up Criteria for Hydroliquefaction Dissolver

Characteristics	Value
Process	
Slurry Flow Rate	30,000 T/D (9 CFS)
Gas Flow Rate (at exit)	623,000 ACFH (173.1 ACFS)
Operating Conditions:	
Temperature	840°F
Pressure	1,225 psia
LHSV (at operating conditions)	1.0
Actual Liquid Retention Time	30 min
Vessel	
Design Pressure	2,000 psi
Design Temperature	900°F
Maximum Wall Thickness	12 inches
Design Code	Division 2
Maximum Vessel Weight	500 tons
Corrosion Protection	Clad with 1/16 in. 316 SS

Flow Distribution

1. Provide a means of assuring uniform liquid and vapor distribution within the vessel.
2. Maximum vertical distance between distributor and redistributor is 20 feet.

Table 9 - Examples of a Number of Equipment Categories Pertinent to Scale-up of Coal Conversion Processes

1. High-Capacity and High-Pressure Coal Slurry Pumps (above 1400 psig)
2. Coal Slurry Preheat Furnaces
3. Coal Slurry Pressure Letdown Valves
4. Pressure Recovery Turbines
5. Large-Capacity Liquid-Solids Separation Methods and Equipment
6. Solids Drying Equipment
7. Large-Capacity Gasifiers
8. Solids Feed Devices for High-Pressure Gasifiers
9. Gas-Solids Separation Equipment Suitable for High Pressures and Temperatures
10. High-Capacity Hydrotreating Equipment
11. Large-Scale Synthesis Reactors
12. Compressors Suitable for Gas-Solids Mixtures and High Pressures

Table 10 - Scale-up: Example PDU and Pilot Plant Dissolver Parameters

Parameter	Process Development Plant Dissolver	Pilot Plant Dissolver
Dissolver Volume, ft^3	3.67	94.25
Dissolver Length, ft	12.0	30.0
Dissolver Diameter, ft	0.62	2.0
LHSV,* hr^{-1}	0.7	1.16
GHSV,** hr^{-1}	110.0	150.7
Gas Flow Rate, ft^3/sec	0.0044	0.093
Slurry Flow Rate, ft^3/sec	0.0071	0.036
Gas Relative Velocity ft/sec	0.7	0.69
Gas Velocity, ft/sec	0.70	0.70
Slurry Velocity, ft/sec	0.0025	0.012
Gas Retention Time, min	0.28	0.71
Slurry Retention Time, min	80.32	41.81
Coal Rate, $lb/hr/ft^3$ Dissolver	14.53	28.0
Coal Feed, T/D	0.64	31.67
Dissolver, L/D	19.4	15.0
Solvent/Coal, lb/lb	(Assumed) 2.0	2.0

*Liquid hourly space velocity
**Gas hourly space velocity

Table 11 - Scale-up: Example Large-Scale Plant Dissolver Design Parameters

Parameter	Process Development Plant Dissolver	Plot Plant Dissolver	Large Plant Dissolver
Dissolver Volume, ft^3	3.67	94.25	32,572 (total)
Dissolver Length, ft	12.0	30.0	69 } 6 Vessels
Dissolver Diameter, ft	0.62	2.0	10 } 6 Vessels
LHSV, hr^{-1}	0.7	1.16	1.0 @ T. & P.
GHSV, hr^{-1}	110.0	150.7	638.0
Gas Flow Rate, ft^3/sec	0.0044	0.093	28.83 } Per Vessel
Slurry Flow Rate, ft^3/sec	0.0071	0.036	1.5 } Per Vessel
Gas Relative Velocity, ft/sec	0.7	0.69	0.7
Gas Velocity, ft/sec	0.70	0.70	0.74
Slurry Velocity, ft/sec	0.0025	0.012	0.038
Gas Retention Time, min	0.28	0.71	0.56
Slurry Retention Time, min	80.32	41.81	30.38
Coal Rate, $lb/hr/ft^3$ Dissolver	14.53	28.0	25.58
Coal Feed, T/D	0.64	31.67	10,000
Dissolver, L/D	19.4	15.0	6.9
Solvent/Coal, lb/lb	(Assumed) 2.0	2.0	2.0

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COLLECTED WORK NO. 6

DEMONSTRATION PLANT

CLEAN BOILER FUELS FROM COAL

PRELIMINARY DESIGN/CAPITAL COST ESTIMATE

R & D REPORT NO. 82 - INTERIM REPORT NO. 1

VOLUME I

Prepared by

THE RALPH M. PARSONS COMPANY

LOS ANGELES, CALIFORNIA

Contract No. 14-32-0001-1234

for

UNITED STATES

DEPARTMENT OF THE INTERIOR

OFFICE OF COAL RESEARCH

WASHINGTON, D.C. 20240

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SECTION 1

INTRODUCTION

The Ralph M. Parsons Company has completed this report which summarizes the preliminary design and capital investment estimate for a demonstration-scale plant to produce clean boiler fuels from coal. This work was done at the request of the Office of Coal Research (OCR).

The objectives of our preliminary design work were:

(1) To establish a preliminary demonstration plant design to effectively produce clean boiler fuels from coal.

(2) To estimate the budget for fixed capital investment requirement for the design, engineering, procurement, and construction of the coal conversion complex.

(3) To estimate the earliest date at which the coal conversion plant could be mechanically complete and ready to begin production operations.

(4) To estimate the required fund drawdown schedule; i.e., the amounts of money that would be expended during each semi-annual period over the life of the project.

The process design bases and yields for this plant were supplied to us by OCR process development contractors and were based on the OCR process design concept which was considered to have the greatest potential for converting a typical coal entirely into desulfurized liquid fuels. To support this work, OCR made arrangements for the Pittsburg & Midway Coal Mining Company (P&M) to supply Parsons a process design basis and supporting technology for coal liquefaction, and with Bituminous Coal Research, Inc. (BCR) to supply a process design basis for the gasification of a coal residue to produce synthesis gas for captive use. Representatives of OCR and these two companies provided these design parameters.

On the basis of information provided by P&M and BCR, OCR instructed Parsons to proceed with a preliminary design which is the first step in a development program to bring coal conversion processes to commercial reality. The design represents substantial engineering judgment for the selection of both the equipment required and the processing conditions to be used to achieve the project's objectives. We understand that this approach is consistent with OCR's attitude to accept potential risks in plant performance and uncertainties in costs in order to speed the development of viable commercial designs. It should be recognized that this preliminary design is based on immature technology and precedes the availability of experimental results from pilot plant operations for the two primary coal conversion steps of liquefaction and production of syngas by the proposed mode of gasification.

During the course of the design assignment, analysis showed that is is possible to achieve the production of desulfurized liquid fuels exclusively when using an alternative approach to syngas production. The current preliminary design employs gasification of a coal residue from the liquefaction plant for this purpose. One alternative is to use the offgases from the liquefaction plant for syngas production rather than for plant fuel. The coal residue could then be gasified, possibly with air, for the production of desulfurized low Btu fuel gas for captive use. The heating values produced by this scheme can be absorbed in the total plant design without introducing a fuel imbalance.

The design criteria do not permit purchase of hydrocarbon feedstocks for plant startup; also, the plan is to include demonstration of production of syngas by gasification of coal or a coal-sourced solid in the design. These objectives could be achieved using the plant modification for syngas described above. With this modification, the gasification operation is removed from the main production line and becomes a service plant producing fuel gas at low pressure. Such a service plant can be designed with as many parallel trains as are required to support a desired design service factor.

A brief description of the approach and the procedures that were used in preparing this document will aid in the rapid essimilation of its contents.

In Section 3, Design Basis, a statement of the primary characteristics of the coal conversion plant and its supporting facilities is presented. In formulating this design basis, the objective of the demonstration plant facility was conceived to be:

- To speed the commercialization of coal conversion processes for production of "clean" fuels from indigenous high sulfur coals

- To leap-frog the pilot plant program and to gain time in the development of commercially viable coal conversion processes

- To provide adequate liquid fuels for prolonged testing in commercial power plant operations

- To provide definition of performance requirements and financial incentive for prompt development of the hardware required for the large-scale coal conversion plants and their test in the demonstration plant facilities

- To demonstrate the operability of commercial scale coal conversion equipment

- To provide a basis for accurate prediction of the economics of commercial scale coal conversion plants

- Following demonstration plant operation, to permit simultaneous design of multiple commercial coal conversion plants

The process description and process block flow diagram presented in Section 4 illustrate, in general terms, the configuration of the coal conversion plant. These items, plus the material and utility balance data shown in Section 5, serve as a basis for the fixed capital investment estimate and scheduling information summarized in subsequent sections.

A budget estimate for the costs of designing, engineering, procuring and constructing the physical facilities is presented in Section 8. Estimates for additional costs such as initial charge of catalysts and chemicals, startup, and initial working capital are also summarized in this section in order to provide an estimate for the total project dollar requirement through plant startup.

The rate of dollar utilization for the design and construction period of the project is shown in Section 9 and is based on the estimated total capital requirements summarized in Section 8 plus the project schedule in Section 10 depicting the work that would be accomplished during the design-construction of the project.

This schedule developed for planning purposes, assumes project activation on January 1, 1974.

The operability, reliability and performance of the demonstration plant is discussed in detail in Section 11, and possible design improvements affecting economics and better reliability are reviewed in Section 12.

The contents of this report provide the basis for the next stage of planning for the creation and utilization of this facility.

SECTION 2

SUMMARY

Parsons has completed a detailed preliminary process design and capital investment estimate for a project to design, engineer, procure, construct, and start up a demonstration-scale plant to produce clean boiler fuels from coal. The results of this work are summarized in this report.

The project plan is based on construction of a demonstration plant in Southern Illinois for preliminary cost estimate purposes. This location was arbitrarily chosen; however, it meets the desired criteria of availability of large resources of high-sulfur coal and a large potential utility/industrial market that has ecological restrictions for high-sulfur coal use.

The design basis was provided by OCR and its process development contractors. The demonstration plant will have the capacity to process 10,000 tons of coal per day and produce approximately 25,000 barrels of liquid products. The primary products consist of two grades of clean boiler fuels; secondary products are a high-grade naphtha and sulfur. The liquid boiler fuels will have an energy content of approximately 145 billion Btu per day, which can generate 620 megawatts of electrical energy based on a 35% efficiency in the power generation step.

The largest quantity boiler fuel will be roughly equivalent to a No. 6 fuel oil, contain 0.5% sulfur, and provide 65% of boiler fuel energy produced. The second boiler fuel will approximate a No. 4 fuel oil with 0.2% sulfur and contain 35% of the fuel product.

All energy to operate the plant will come from by products produced from coal to the process units.

The coal conversion process plants will consist of a coal liquefaction unit and a gasifier unit to produce synthesis gas (syngas) from coal-derived materials. Ten thousand tons of coal per day will be fed to the liquefaction unit, which is a modified SRC plant. This unit will dissolve the majority of the feed coal in a coal-derived solvent in the presence of reducing gases at elevated temperatures and pressures. The lighter clean boiler fuel, containing 0.2% sulfur, will be produced by hydrodesulfurization (HDS) of a portion of the de-ashed solvent refined coal produced in this process plant. The filter cake, produced during the process of separation of residual coal and liquid products, will go to the gasifier unit where it will be reacted with steam and oxygen at elevated temperature and pressure to produce the hydrogen-containing reducing syngas required for the operation of the modified SRC unit. By-product gases produced will be burned captively as fuel to produce the necessary steam and electrical energy required to operate the complex.

An artist's conception of the plant is presented. The preliminary estimate is that the facilities will occupy approximately 350 acres; a site containing 600-plus acres is recommended.

A fixed-capital investment estimate was developed by Parsons for use in planning future budgets; estimate is preliminary and is targeted to be within the -5 to +20% accuracy range, based upon the process shown in Section 4, utilizing historical in-house costs and factors to determine final plant constructed costs.

The estimated fixed capital investment is $270 million.

Included in the $270-million estimate are the necessary ancillary facilities such as administration, laboratory, cafeteria, maintenance, warehouse, and other related buildings and equipment, maintenance equipment, road paving, fire prevention, and utilities distribution systems required to efficiently operate this grass-roots complex in Southern Illinois.

In addition to the fixed capital investment for these physical facilities, it is estimated that an additional investment of $40 million would be required to carry the project through the startup period. These additional funds are for such items as initial charge of catalysts and chemicals, plant startup expenses, and initial working capital. The total budget project capital estimate, excluding interest during construction, therefore, is approximately $310 million for the period through startup. Depending on the financing arrangements used, the interest during construction is expected to be in the range of zero to $50 million. Direct standard operating costs for the plant startup period would be in addition to this cost.

A project schedule has been prepared for use in planning. This schedule indicates that a demonstration plant could be designed and constructed to a point of mechanical completion by the third quarter of 1977, assuming contract award on January 1, 1974. Production from this clean boiler fuel facility would be expected during Calendar Year 1978. This schedule is based on award of full project responsibility to a major contractor such as Parsons.

A fund requirement schedule has been prepared based on the estimated $310-million budget capital investment requirement and the project schedule. The fund requirement schedule, showing estimated expenditures on a semiannual basis, would build progressively through Fiscal Years 1974 and 1975, and peak in the last half of Fiscal Year 1976 at approximately $86 million; total expenditures in Fiscal Year 1976 would be approximately $134 million plus interest. Details of the fund requirement schedule, adequate for use as an appropriation schedule guide, are shown in Section 9; interest burden during construction must be added to these values.

There are a number of uncertainties in this current design, which is based on immature technology and precedes the availability of experimental results from pilot-plant operations for the two primary coal conversion steps of liquefaction and production of syngas by the specified mode of gasification. The future development program should include input of data from the total coal conversion program laboratory and pilot-plant work to confirm and substantiate the design. We understand that OCR intends to support this plan. Recommendations for a program to develop the required data and performance inputs are presented in this report and additional recommendations will follow.

At this point in time, it is not practical to predict a standard of performance if the plant is constructed based on this preliminary design. We recommend that further consideration be given to certain design modifications to permit the employment of as much developed technology as practical without sacrificing or compromising the project.

Supplementary reports containing a summary of profitability analyses plus additional design and equipment detail will be issued during October 1973.

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COLLECTED WORK NO. 7

DEMONSTRATION PLANT

CLEAN BOILER FUELS FROM COAL

PRELIMINARY DESIGN/CAPITAL COST ESTIMATE

R & D REPORT NO. 82 - INTERIM REPORT NO. 1

VOLUME II

Prepared by

THE RALPH M. PARSONS COMPANY

LOS ANGELES, CALIFORNIA

Contract No. 14-32-0001-1234

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UNITED STATES

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SECTION 1
INTRODUCTION

This second volume completes the technical report by The Ralph M. Parsons Company for the preliminary design and capital cost estimate of a demonstration-scale plant to produce clean boiler fuels from coal. Included in this volume are the various flow diagrams and material balance data necessary to substantiate the preliminary design bases of the demonstration plant as referenced and presented in Volume I. This work was done at the request of the Office of Coal Research (OCR).

The demonstration plant as defined in Volumes I and II will have the capacity to process 10,000 tons of coal per day and to produce approximately 25,000 barrels of liquid products. The primary products consists of two grades of clean boiler fuels; secondary products are a high-grade naphtha and sulfur.

The prime objectives and overall plant preliminary design work were covered in Volume I, dated September 21, 1973. These preliminary design objectives were:

(1) To establish a preliminary demonstration plant design to effectively produce clean boiler fuels from coal.

(2) To estimate the budget for fixed capital investment requirement for the design, engineering, procurement, and construction of the coal conversion complex.

(3) To estimate the earliest date at which the coal conversion plant could be mechanically complete and ready to begin production operations.

(4) To estimate the required fund drawdown schedule; i.e., the amounts of money that would be expended during each semi-annual period over the life of the project.

The process design bases and yields for this plant were supplied to Parsons by OCR process development contractors and were based on the OCR process design concept which was considered to have the greatest potential for converting a typical coal entirely into desulfurized liquid fuels. To support this work, OCR made arrangements for the Pittsburg & Midway Coal Mining Company (P&M) to supply Parsons a process design basis and supporting technology for coal liquefaction, and with Bituminous Coal Research, Inc. (BCR) to supply a process design basis for the gasification of a coal residue to produce synthesis gas for captive use. Representatives of OCR and these two companies provided these design parameters.

On the basis of information provided by P&M and BCR, OCR instructed Parsons to proceed with a preliminary design as the first step in a development program to bring coal conversion processes to commercial reality. The design represents substantial engineering judgment for the selection of both the equipment required and the processing conditions to be used to achieve the project's objectives. Parsons understands that this approach is consistent with OCR's philosophy of accepting potential risks in plant performance and uncertainties in costs in order to speed the development of viable commercial designs. After completion of this first step, design refinements may be possible with desirable improvements in economics, operability, utilities consumption, and overall plant thermal efficiency.

It should be recognized that this preliminary design is based on immature technology and precedes the availability of experimental results from pilot plant operations for the two primary coal conversion steps of liquefaction and production of syngas by the proposed mode of gasification.

To supplement Volume I, the overall plant process description, process flow block diagram, and material balance data are presented in Section 2. As a further aid, the more detailed process flow diagrams for each of the various unit areas of the demonstration plant are presented in Section 3. Material balances for each of these vital process areas are included on each of the process flow diagrams.

For convenience, a listing of all major equipment shown and required in the various unit area process flow diagrams is included in Section 4, Major Equipment Summary. The equipment cost for each of the process areas is presented in the Unit Cost Tabulation (Section 5).

Finally, the plot plan of Section 6 envisions the demonstration plant layout as required for a major grass-roots plant complex. As indicated, the total area is about 300 acres for the building and process areas. Land allotments are based upon a preliminary layout of projected process equipment and ancillary facilities for the total complex.

SECTION 2

PROCESS DESCRIPTION

The process configuration is depicted in the overall process flow block diagram, Figure 1, which immediately follows this section. For convenience of presentation, the clean boiler fuel plant complex is described as being composed of three major parts: (1) coal preparation, (2) a coal liquefaction section, and (3) a gasification section.

The clean boiler fuel complex is designed to charge 10,000 tons of coal per day, and to produce as its major products two low-sulfur liquid fuel streams. The two forms of fuel will consist of a liquid product containing approximately 0.5 weight percent sulfur, sufficient to fuel a 400-megawatt power plant, and a desulfurized distillate fuel oil product containing 0.2 weight percent sulfur, sufficient to fuel a 200-megawatt power plant. By-products consist of hydrotreated naphtha and the sulfur recovered from the various desulfurizing processes. The light hydrocarbons produced are burned for plant fuel.

A coal liquefaction process is being developed by the Pittsburg and Midway (P&M) Coal Mining Company under contract to the OCR; it produces de-ashed fuels from coal. Data and experience from the P&M work have been used as background for this design. A gasification process is being developed by Bituminous Coal Research, Inc. (BCR), also under contract to the OCR; background data from the BCR work, as well as other sources, have been used in this design. The gasification process will convert wet filter cake from the liquefaction section to the reducing gas required for the operation of the liquefaction process.

COAL SUPPLY

Run-of-mine coal will be purchased. The clean boiler fuel complex will store a three-day supply, and will prepare it for feed to the process units as described in the subsections that follow.

COAL RECEIVING, STOCKPILING, AND RECLAIMING

Coal is received at the rate of 12,500 tons per day. A rail car dumper dumps each car into a hopper below rail level. This hopper can also receive coal from mine trucks. A vibrating feeder feeds the coal onto a belt conveyor that transfers it to a rail-mounted slewing stacker, which places it in storage. The stockpile will hold 37,500 tons of coal, or a three-day inventory. Compactors have been provided for compacting the stockpile, if needed.

Reclaiming is done by a bucket wheel, mounted on tires, feeding a transverse conveyor to one of the two reclaim belt conveyors. A transverse conveyor takes the coal from either of the reclaim conveyors and delivers it to the coal preparation plant for washing.

The stockpiling system will handle 900 tons of coal per hour, and the reclaim system will handle 800 tons per hour.

COAL PREPARATION, DRYING, AND GRINDING

The flow sequence for this section is shown in Figure 2, Unit Area 10 Coal Preparation. Coal containing an average of about 10% moisture is reclaimed from the stockpile and conveyed to a 300-ton bin. A 60-inch reciprocating plate feeder removes the coal from the bin and places it on a 48-inch belt conveyor, fitted with a tramp iron magnet, which feeds an 8- by 20-foot scalping screen. The 3-inch, plus, coal is fed to a rotary coal breaker. Oversize refuse from the breaker is returned to the mine for burial. The broken coal (3-inch, minus) is placed on a 48-inch belt conveyor, where it is combined with the undersize coal from the screen and dumped onto an 8,000-ton storage pile.

Coal is withdrawn from the storage pile and conveyed to the washing plant, where a series of jigs, screens, centrifuges, cyclones, and a roll crusher clean the coal and reduce it to minus 1-1/4 inches. Refuse from this operation is also returned to the mine area for disposal. Wet fine refuse is pumped to settling ponds.

The clean 1-1/4-inch, minus, coal is then dried in a flow dryer and reduced to 1/8-inch, minus, in two Cage-Paktor pulverizers for dissolver feed. The coal liquefaction equipment is shown in Figure 3, Coal Slurrying, Liquefaction, and Distillation. To prepare the feed to the SRC unit, the dried, ground coal is transferred by conveyor to the coal solvent slurry tank; 10,000 tons of coal and 20,000 tons of recycle solvent per day are metered into this tank. The slurry of 1/8-inch, minus, coal in SRC solvent is pumped through a low-pressure loop that feeds high-pressure pumps; these pumps transfer the slurry to the dissolvers at pressure up to 1,000 pounds per square inch. Excess slurry in the loop is returned to the slurry tank.

LIQUEFACTION PROCESS

This section includes the coal slurrying, dissolving, and distillation operations that are shown in Figure 3. Acid gas removal facilities, serving as an auxiliary to this section, are shown in Figure 4, Unit Area 13 Dissolver Acid Gas Removal.

The feed -- 10,000 tons per day of 1/8-inch, minus, coal -- is combined with unfiltered solvent to form a 50 weight percent slurry, which is pumped to the preheat furnace. The slurry is combined with syngas and water; the resulting mixture is preheated, and fed to the reactor, which is operating at about 850°F and 1,000 psig. The produce mixture from this reaction system consists of a liquid phase, a solid phase of ash plus undissolved coal, and a gas phase. The gas phase is separated, scrubbed to remove hydrogen sulfide and carbon dioxide, and its major portion is combined with make-up syngas and recycled to the feed. The excess gas is released to the fuel system. The solid phase is separated from a portion of the liquid phase by means of filtration, and is then transferred to the gasification plant, where the residual carbonaceous material is gasified to produce syngas. The remainder of the unfiltered dissolver liquid product, containing undissolved coal particles, is used for recycle to slurry the feed coal.

The liquid-phase filtrate produced in the filtration operation passes to a separation section, where it is fractionated to produce a naphtha stream, a distillate that will be desulfurized to become light boiler fuel, and the residual fuel oil. The residual fuel oil will have a sulfur content of about 0.5 weight percent, and is an adequate quantity to fuel a 400-megawatt power plant.

FUEL OIL HYDROGENATION

The flow sequence for this process is shown in Figure 5, Unit Area 15 Fuel Oil Hydrogenation. Feed to this unit is the distillate stream produced in the distillation unit. A portion of the product from this unit is used as absorption oil to recover phenols from process water. The phenol-laden absorption oil is mixed with the distillate fresh feed, combined with hydrogen gas, preheated to reaction temperature, and reacted in contact with desulfurization catalyst to convert the sulfur and nitrogen content of the oil to hydrogen sulfide and ammonia. Reactor effluent is separated into a gas, which is recycled, and a liquid, which is stripped of light ends and naphtha. The naphtha is directed to the naphtha hydrogenation unit, and the stripped product is cooled and directed to storage as a light fuel oil product containing a maximum of 0.2% sulfur. This product is an adequate quantity to supply fuel for a 200-megawatt power plant.

NAPHTHA HYDROGENATION

The flow sequence and material balance for this process are shown in Figure 6, Unit Area 16 Naphtha Hydrogenation. Light liquid produced in the coal liquefaction process plus naphtha formed during the SRC distillate hydrogenation step are combined, and are hydrotreated to remove additional sulfur and nitrogen. The levels of nitrogen and sulfur in the product naphtha will be reduced to approximately 5 and 1 parts per million, respectively. The composition and purity of this high-quality naphtha will make it suitable for sale.

FUEL GAS SULFUR REMOVAL

The sequence of flow and material balance for this facility are shown in Figure 7, Unit Area 17 Fuel Gas Sulfur Removal. Low-pressure gases produced in the various units are combined and fed to the fuel gas sulfur removal unit, where the carbon dioxide and hydrogen sulfide are removed. The hydrogen sulfide is converted to sulfur in the sulfur recovery unit; the carbon dioxide is vented to the atmosphere. The sulfur plant includes a tail gas purification unit, and produces an effluent that meets existing environmental requirements. The "sweet" gases, following removal of carbon dioxide and hydrogen sulfide, are used as fuel within the plant.

GASIFIER

The flow scheme and material balance for this unit are shown in Figure 8, Unit Area 18 Gasification. Wet filter cake from the liquefaction process is fed to a slagging, suspension-type gasifier unit, where it is contacted with steam and oxygen at an elevated temperature of 3,000°F and a pressure of 200 psig. The carbonaceous material is gasified and produces primarily synthesis gas (carbon monoxide and hydrogen). The oxygen required for the operation of this unit is captively produced.

The synthesis gas product from the gasifier is passed through heat recovery boilers, coarse char cyclones, and a venturi scrubbing system. Solids containing carbon are reclaimed and recycled to the slagging section of the gasifier unit.

The cooled synthesis gas is then treated for carbon dioxide and hydrogen sulfide removal by absorption in the acid gas removal system. The off-gas (hydrogen sulfide) stream is sent to the sulfur plant for treatment and recovery of sulfur values. The flow sequence and material balance for this auxiliary facility are shown in Figure 9, Unit Area 19 Acid Gas Removal.

Most of the purified gas effluent from the acid gas removal system is used directly as a reducing gas in the coal liquefaction plant. Gas not sent directly to the liquefaction section is converted to high-purity hydrogen that is used in the fuel oil and naphtha hydrogenation unit. The slag that is produced in the gasification unit is solidified and transported to a storage pile located in the vicinity of the feed coal storage pile. The slag will be removed from the site as a back-haul item for the coal supply trains.

HYDROGEN MANUFACTURE

High-purity hydrogen manufacture employs three processing steps -- shift conversion, CO_2 removal, and methanation. The sequence of flow and material balance relating these steps is shown in Figure 10.

Sweet gas produced in the gasification unit is fed to the hydrogen manufacturing section, where it is first subjected to shift conversion whereby carbon monoxide reacts with steam to produce hydrogen and carbon dioxide. The gas from shift conversion is sent to a carbon dioxide removal step and a final methanation unit, where residual carbon dioxide and carbon monoxide are converted to methane; this hydrogen stream is then fed to the product distillate and naphtha hydrogenation unit.

WATER TREATMENT

Raw water treatment is shown in Figure 11, which indicates the treatment necessary for raw water usage for domestic, boiler, and cooling-tower makeup consumptions.

The treatment sequence of process waters is shown in Figures 12 and 13. Process waters from the operations in the plant are collected into two streams, one a nonphenolic water stream and the other a phenolic-bearing water. These waters are settled, and entrained oil is skimmed from them; they are then steam-stripped to remove hydrogen sulfide and ammonia. The phenolic water receives a contact with absorption oil to extract the phenolic content of the water. The phenols are returned, with the absorption oil, to the fuel oil hydrogenation unit, where they are hydrogenated and converted to benzene or related compounds.

Treated, stripped process water is returned for reuse in the process area from which it came. An arbitrary volume of stripped water is directed to disposal via a biological treatment pond to purge the system of impurities that may build up.

COLLECTED WORK NO. 8

DEMONSTRATION PLANT

CLEAN BOILER FUELS FROM COAL

PRELIMINARY DESIGN/ECONOMIC ANALYSIS

R & D REPORT NO. 82 - INTERIM REPORT NO. 1

VOLUME III

Prepared by

THE RALPH M. PARSONS COMPANY

PASADENA, CALIFORNIA

Contract No. 14-32-0001-1234

for

UNITED STATES

DEPARTMENT OF THE INTERIOR

OFFICE OF COAL RESEARCH

WASHINGTON, D. C. 20240

SECTION 1

INTRODUCTION

This report (Volume III) summarizes a preliminary economic analysis for a demonstration plant designed to produce clean boiler fuels from coal. The preliminary design and capital cost estimate were summarized in Volume I, dated September 21, 1973, and Volume II, dated November 2, 1973.

The prime objectives of this work are described in Volume I. The process design bases and yields for this plant were supplied to Parsons by Office of Coal Research (OCR) process development contractors (referenced in Volume I), and were based upon the OCR process design concept that was considered to have the greatest potential for converting a typical coal entirely into desulfurized liquid fuels. For reference, the design bases are included in the Appendix to this report.

The profitability analysis presented herein is based on the design published in Volumes I and II. Parsons intends to perform additional design improvement work.

The demonstration plant will have the capacity to process 12,500 tons per day (TPD) of run-of-mine coal and to produce approximately 25,000 BPD of liquid products. Feed to the coal conversion plant will be 10,000 TPD of washed, sized coal. The primary products consist of two grades of clean boiler fuels; secondary products are high-grade naphtha and sulfur.

Commercial plants will be larger than the demonstration plant. The economics of larger-scale production are expected to improve the profitability and allow lower product selling prices than those available from this demonstration plant.

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SECTION 2

SUMMARY

A preliminary design and an economic evaluation have been developed for a grassroots coal liquefaction complex to convert 10,000 tons per stream day of washed, sized coal to approximately 25,000 bbl/day of liquid products containing approximately 156,700 million (MM) Btu/day of useful energy. The economic evaluation results are presented herein.

Investment and economic estimates are based on mid-1973 prices. The average product selling prices are calculated at $11.23/bbl or $1.78/MM Btu, assuming private ownership, 65/35 debt/equity ratio, 7-1/2% interest rate, run-of-mine coal at $5.75/ton, and a 10% discounted cash flow (DCF) return on equity.

If government ownership and operation of the demonstration plant are assumed, to break even (return invested capital without interest) over a 10-year operating period, the average product selling price must be $8.84/bbl or $1.40/MM Btu.

Other cases studied are summarized in Table 2-1, and are presented in more detail in Section 7. Sensitivity to variations in coal cost, investment cost, and profitability levels are calculated and shown in greater detail in Section 8.

Table 2-1 - Summary of Average Product Selling Prices Based on Coal at $5.75/ton Run of Mine

Ownership	10-yr Project Life, 0% DCF ($/MM Btu)	DCF[a] for 20-yr Project Life		
		0% ($/MM Btu)	10% ($/MM Btu)	20% ($/MM Btu)
Government (not taxed)	1.40	1.08		
Private (100% equity)	1.61	1.21	2.12	3.62
Private (65% debt, 7-1/2% interest)	1.75	1.40	1.78	2.44
Private (65% debt, 9% interest)	1.79	1.45	1.85	2.51

[a]DCF = discounted cash flow.

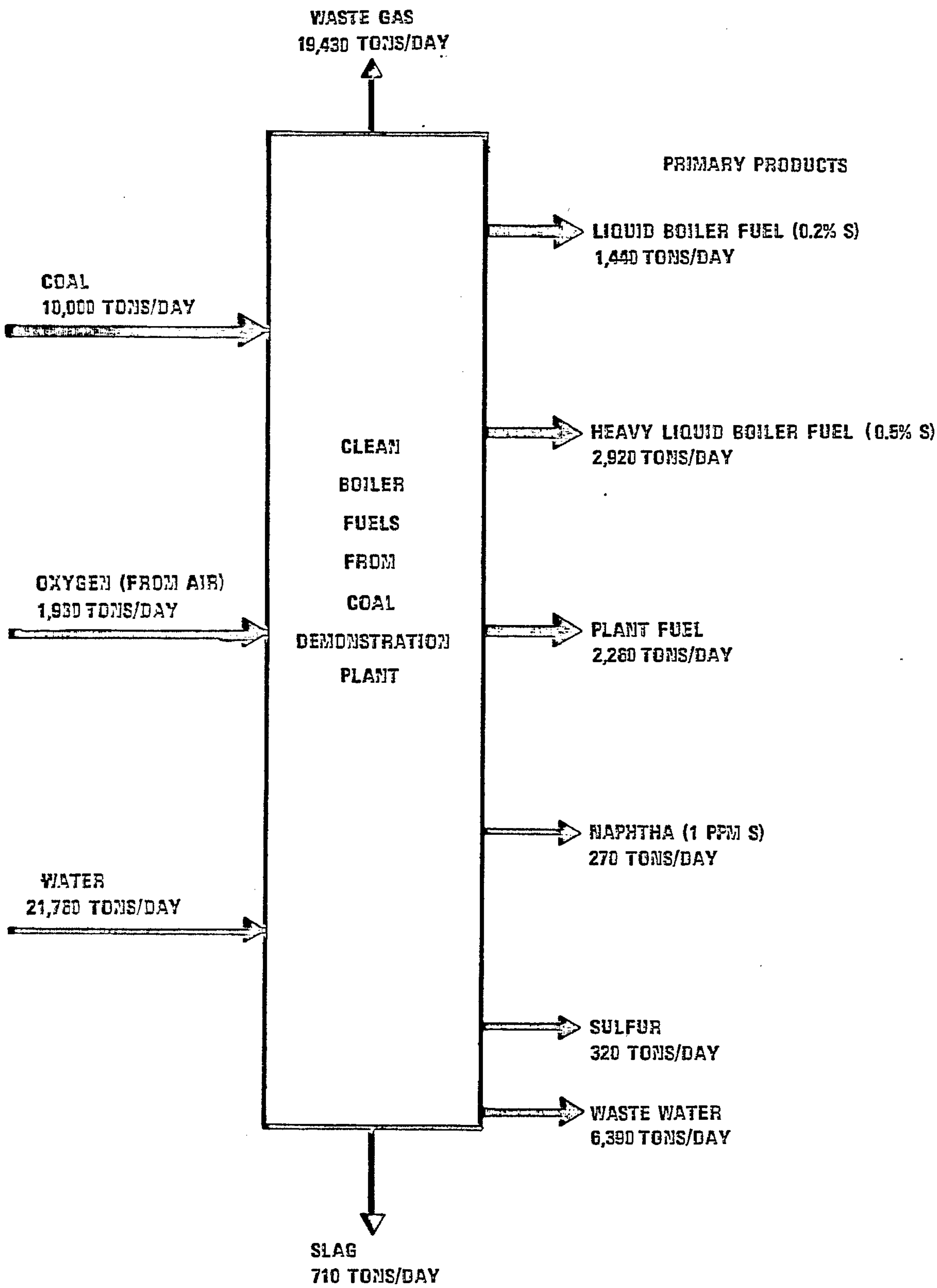

Figure 3-2 - Overall Material Balance

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COLLECTED WORK NO. 9

DESIGN OF A DEMONSTRATION PLANT TO PRODUCE CLEAN OILS FROM COAL

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FEBRUARY 25, 1974

ABSTRACT

At the request of the Office of Coal Research (OCR), The Ralph M. Parsons Company has completed a study of preliminary design and estimated capital investment for a demonstration-scale plant to produce two types of clean low-sulfur, high-Btu oils from coal. Design objectives were to: establish an effective plant design; estimate capital investment requirements; estimate the earliest possible production date; estimate each budget period during construction; shorten lead time for commercial coal-conversion processes; provide enough liquid fuels for power-plant testing; specify performance parameters and financial incentives for immediate design of conversion plant hardware; demonstrate efficiency of commercial-scale plant equipment; provide a basis for economic predictions regarding commercial plants; and enable concurrent design of multiple plants.

The demonstration plant is designed to process 10,000 tons of coal daily. It contains two primary process units: (1) a modified solvent refined coal unit, and (2) a gasifier producing syngas (SNG). Plant processes include three major divisions: (1) coal preparation, (2) coal liquefaction, and (3) gasification. The plant is designed to produce a pair of low-sulfur liquid fuel streams. The first stream will produce approximately 0.5 weight percent sulfur, sufficient to provide fuel for a 400,000-kW power plant; the second is fuel oil containing 0.2 weight percent sulfur, adequate for a 200,000-kW plant. By-products are hydrotreated naphtha and recovered sulfur. The plant could be converted to produce approximately 67 million cubic feet of SNG daily. Estimated total fixed capital investment is $270 million.

Tables and illustrations at end of paper.

INTRODUCTION

At the request of the Office of Coal Research (OCR), The Ralph M. Parsons Company has completed a study of preliminary design and estimated capital investment for a demonstration-scale plant to produce clean low-sulfur, high-Btu oils of two types from coal. A demonstration-scale plant is defined for these purposes as one of sufficient size to demonstrate the commercial viability of the technology employed as well as product performance. This includes predictions of operating economics and sufficient design confidence for simultaneous design of multiple commercial units, based on experience acquired during design and operation of the demonstration plant.

Process design bases and yields for this plant were provided by OCR process development contractors. These were based on the OCR process design concept adjudged to have the greatest potential for converting a typical coal entirely into desulfurized and deashed liquid fuels.

On the basis of information provided by other OCR contractors, a preliminary design was developed as the first step in a program to bring coal conversion processes to commercial reality. The design incorporates much engineering research - for selection of equipment required as well as for development of processing techniques to achieve project objectives.

This approach is consistent with OCR's acceptance of potential risks in plant performance and cost uncertainty in order to speed the development of viable commercial designs. It should be recognized that this preliminary design is based on immature technology. It precedes the availability of experimental results from pilot-plant operations for the two primary coal conversion steps, which are liquefaction and production of synthesis gas (syngas) by a proposed mode of gasification.

Design Objectives

Objectives of the preliminary design work were:

(1) To establish a demonstration plant design to effectively produce low-sulfur oils from coal. Oils produced are to be cleanly combustible boiler fuels meeting applicable environmental protection codes.

(2) To estimate capital costs of design, engineering, procurement, and construction of the coal conversion complex.

(3) To provide an estimate of the earliest possible startup date for the coal conversion plant.

(4) To develop a budget including planned expenditures of funds during each semiannual period over the life of the project.

Demonstration Plant Goals

The demonstration plant facility was conceived to meet the following goals:

(1) Foster early commercialization of coal conversion processes to produce clean fuels from indigenous high-sulfur coals.

(2) Gain time in development of commercially viable coal conversion processes by leapfrogging the pilot-plant program.

(3) Provide adequate liquid oil fuels for prolonged testing in commercial power plant operations.

(4) Define performance requirements and financial incentives for prompt development of hardware required for large-scale coal conversion plants, and to test these in demonstration plant facilities.

(5) Demonstrate the operability of commercial-scale coal conversion equipment.

(6) Provide a basis for accurately predicting the economic viability of commercial-scale coal conversion plants.

(7) Following demonstration plant operation and application of resulting data, permit simultaneous design of multiple commercial coal conversion plants.

The process description and process block flow sketch included here define, in general terms, the configuration of the coal conversion plant. These items, plus material and utility balances and equipment lists, are the bases for the fixed capital investment estimate and scheduling information summarized in subsequent sections.

Budget estimates for the costs of designing, engineering, procuring, and constructing the physical facilities are presented. Estimates for additional costs such as initial charge of catalysts and chemicals, startup, and initial working capital are summarized to provide an estimate for the total project dollar requirement through plant startup.

The spending rate for design and construction of the project is given, based on the estimated total capital requirements plus the project schedule.

Operability, reliability, and performance of the demonstration plant are discussed. Possible design improvements affecting economics and better reliability are reviewed.

The information presented in this paper provides the basis for the next stage of planning for the facility.

DESIGN BASIS

The design basis, key characteristics, and products of the oil fuel manufacturing facility to process 10,000 tons per day of coal are covered in this section. The basis for this design is a grass-roots manufacturing complex located in southern Illinois. In addition to coal receiving/handling facilities and the process plants required for the production of fuels, the complex will contain all necessary supporting facilities to properly serve the needs of administrative, operating, maintenance, development, and service personnel. An artist's concept of the facility is shown in Figure 1.

Products expected are listed in Table 1; raw materials are tabulated in Table 2.

Primary Process Units

The plant will contain two primary process units:

(1) A modified solvent refined coal (SRC) unit.

(2) A gasifier unit to produce syngas. The unit is being modified from a process under development and has the following characteristics:

(a) Sufficient capacity to supply reducing gases for the SRC dissolver, SRC liquefied coal hydrogenation, and light oil hydrogenation.

(b) The feed to gasifier unit consisting of equal weights of dry filter cake and filtrate from SRC unit.

Processing Scheme Elements

Phenolics/cresylics will be recycled to extinction by returning this stream to the light oil hydrogenator. A fixed-bed hydrogenator will be used for the SRC distillate hydrogenation.

Effluent Treatment and Noise Control

All effluent streams will be treated to meet applicable environmental standards.

Solid disposal will be integrated with coal delivery to provide haulaway and disposal. Equipment will be designed to meet OSHA noise level specifications.

Raw Material and Product Storage

Inventory of raw materials and products will be: coal, 3 days; products, 30 days.

PROCESS DESCRIPTION

The process configuration is depicted in the block process flow diagram, shown as Figure 2. To simplify, the clean boiler-fuel plant complex is described under three major headings: (1) coal preparation, (2) a coal liquefaction section, and (3) a gasification section.

The complex is designed to charge 10,000 tons per day of coal and to produce two low-sulfur liquid fuel streams as its major products. The two forms of fuel will consist of a liquid product containing approximately 0.5 weight percent sulfur, sufficient to fuel a 400-megawatt power plant - and a desulfurized distillate fuel oil product containing 0.2 weight percent sulfur, sufficient to fuel a 200-megawatt power plant. By-products consist of hydrotreated naphtha and sulfur recovered from the various desulfurizing processes. The light hydrocarbons produced are burned for plant fuel.

If the plant were given an alternate product objective, it could convert the gas streams to produce approximately 67 million cubic feet per day of SNG. In this case, a portion of the liquid fuels produced would be consumed for in-plant energy needs.

The SRC process is being developed to produce low-sulfur deashed fuels from coal. Data and experience from this work have been used as background for this design. The Bi-Gas gasification process also is being developed under contract to the Office of Coal Research; data from this work and other sources have also been used in this design. The gasification process will convert wet filter cake from the liquefaction section to reducing gas required for operation of the liquefaction process.

Coal Supply

Run-of-mine coal will be purchased. The clean boiler-fuel complex will store a 3-day supply and prepare it for feed to the process units in the following way.

Coal Receiving, Stockpiling, and Reclaiming

Coal is received at the rate of 12,500 tons per day. A rail car dumper dumps each car into a hopper below rail level. This hopper can also receive coal from mine trucks. A vibrating feeder feeds the coal onto a belt conveyor that transfers it to a rail-mounted slewing stacker, which places it in storage. The stockpile will hold 37,500 tons of coal, a 3-day inventory. Compactors will be provided for compacting the stockpile if needed.

Reclaiming is done by a bucket wheel, mounted on tires, feeding a transverse conveyor to one of the two reclaim belt conveyors. A transverse conveyor takes the coal from either of the reclaim conveyors and delivers it to the coal preparation plant for washing.

The stockpiling system will handle 900 tons of coal per hour, and the reclaim system 800 tons per hour.

Coal Preparation, Drying, and Grinding

Coal containing an average of about 10 percent moisture is reclaimed from the stockpile and conveyed to a 300-ton bin. A 60-inch reciprocating plate feeder removes coal from the bin and places it on a 48-inch belt conveyor fitted with a tramp iron magnet, which feeds an 8-by-20-foot scalping screen. The 3-inch-plus coal is fed to a rotary coal breaker. Oversize refuse from the breaker is returned to the mine for burial. The broken coal (3-inch-minus) is placed on a 48-inch belt conveyor where it is combined with the undersize coal from the screen and dumped into an 8,000-ton storage pile.

Coal is withdrawn from the storage pile and conveyed to the washing plant where a series of jigs, screens, centrifuges, cyclones, and a roll crusher clean the coal and reduce it to minus 1-1/4 inches. Refuse from this operation is also returned to the mine area for disposal. Wet fine refuse is pumped to settling ponds.

The clean minus 1-1/4-inch coal is then dried in a flow dryer and reduced to minus 1/8 inch in two pulverizers for dissolver feed.

To prepare the feed to the SRC unit, the dried, ground coal is transferred by conveyor to the coal solvent slurry tank; 10,000 tons of coal and 20,000 tons of recycle solvent per day are metered into this tank. The slurry of minus 1/8-inch coal in SRC solvent is pumped through a low-pressure loop that feeds high-pressure pumps; these pumps transfer the slurry to the dissolvers at pressures up to 1,000 pounds per square inch. Excess slurry in the loop is returned to the slurry tank.

Liquefaction

The feed, containing 10,000 tons per day of minus 1/8-inch coal as a 50-weight-percent slurry in a recycle solvent, is charged to a reactor where it is contacted with a reducing gas at about 850°F and 1,000 psig. The mixture from this reaction system consists of a liquid phase, a solid phase of ash plus undissolved coal, and a gas phase.

The gas phase is separated and largely recycled after controlling the level of impurities. The solid phase is separated from a portion of the liquid phase by means of filtration, and is then transferred to the gasification plant where residual carbonaceous material is gasified to produce SNG. The remainder of the unfiltered dissolver liquid product containing undissolved coal particles is used for recycle to slurry the feed coal.

The liquid phase filtrate produced in the filtration operation passes to a separation section where it is fractionated to produce a naphtha stream, a distillate that will be desulfurized to become light boiler fuel, and the residual fuel oil. The residual fuel oil will have a sulfur content of about 0.5 weight percent. Enough residual oil will be produced to fuel a 400-megawatt power plant.

The distillate fraction of the coal liquefaction product is catalytically hydrogenated to produce the light fuel oil containing a maximum of 0.2 percent sulfur. It is suitable for a 200-megawatt power plant.

Light liquid produced in the coal liquefaction process plus naphtha formed during the SRC distillate hydrogenation step are combined and hydrotreated to remove additional sulfur and nitrogen. The levels of sulfur and nitrogen in the product naphtha will be reduced to approximately one and five parts per million, respectively. The composition and purity of this high-quality naphtha make it suitable for sale.

Gases produced in the various units are combined and fed to the acid gas removal plant where the carbon dioxide and hydrogen sulfide are removed. Hydrogen sulfide is converted to sulfur in the sulfur recovery unit, while the carbon dioxide is vented to the atmosphere. The sulfur plant includes a tail gas purification unit. Effluent meets all existing environmental restrictions. "Sweet" gases, after removal of carbon dioxide and hydrogen sulfide, are used as fuel within the plant.

Gasification

Wet filter cake from the liquefaction process is fed to a slagging, suspension-type gasifier unit, where it meets steam and oxygen at an elevated temperature of 3,000°F and 200 psig pressure. Carbonaceous material is gasified and primarily produces a syngas (carbon monoxide and hydrogen). Oxygen required for operation of this unit is produced in the plant.

Syngas from the gasifier is passed through heat recovery boilers, coarse char cyclones, and a venturi scrubbing system. Solids containing carbon are reclaimed and recycled to the slagging section of the gasifier unit.

Cooled syngas is then treated for carbon dioxide and hydrogen sulfide removal by adsorption in the acid gas removal system. The off-gas (hydrogen sulfides) stream is sent to the sulfur plant for treatment and recovery of sulfur values.

Most purified gas effluent from the acid gas removal system is used directly as reducing gas in the coal liquefaction plant. Gas not sent directly to the liquefaction section is shift-converted, whereby carbon monoxide reacts with steam to produce hydrogen and carbon dioxide.

Gas from shift conversion is sent to a carbon dioxide removal step and a final methanation unit where residual carbon dioxide and carbon monoxide are converted to methane. The resulting hydrogen stream is then fed to the product distillate and naphtha hydrogenation unit.

Slag produced in the gasification unit is solidified and transported to a storage pile near the feed coal storage pile. Slag will be removed from the site as a back-haul item for the coal supply trains.

The overall material balance is shown in Figure 3.

THERMAL EFFICIENCY

The thermal efficiency of the plant design can be shown by a detailed analysis of the energy balances around the separate process units (Figure 4) and the overall energy balance (Figure 5). Thermal efficiency of the demonstration plant is defined as gross heating value of all products, less utility duties, divided by the gross heating value of the feed coal.

As shown in Figure 4, unit efficiencies are generally high--except for the dissolver at 89.2% and the hydrogen purification units at 61.0%. Despite these high individual unit efficiencies, estimated overall thermal efficiency for this plant is 63.5%.

Stream calculations used in the design of the demonstration plant are based upon product yields and compositions supplied by OCR development contractors. While the mass of the streams does balance, there is an inconsistency in elemental balances. To arrive at a thermal efficiency figure, it was necessary to restate the overall material balance so that an elemental balance is obtained for each element in the feed (carbon, hydrogen, nitrogen, sulfur, and oxygen). As a result, the stream flow rate for thermal balance will be slightly different from those used for equipment design.

MAJOR EQUIPMENT SUMMARY

The major equipment items for each unit process area shown on the process block-flow diagram were the basis for the capital investment estimate. An example is shown in Table 3.

Oxygen plant and coal preparation areas are excluded--as are the CO_2 removal area, Unit 21, and the sulfur plant, Unit Area 23. The last two areas are both considered proprietary processes. Unit area equipment sizes and descriptions are shown in Table 3 by equipment item number designation.

Individual process flow diagrams, material balances, and details of process equipment items for the various unit areas will be available later.

A preliminary fixed capital investment was developed for a grass-roots liquid fuels complex including principal process units previously described.

Necessary ancillary facilities are administration, warehouse, laboratory, change house, cafeteria, and related buildings and equipment; computer and communications systems; rolling stock (including trucks and automobiles for transport within the complex); road paving; utilities distribution; and other items required for an industrial complex of this magnitude.

Total major equipment and total constructed costs were developed for each process area. An example is shown in Table 4. To these costs were added home office engineering, escalation, and sales tax costs, resulting in the total project fixed capital investment cost shown in Table 5, which lists major equipment costs and estimated constructed costs for each unit area. Total major equipment cost for all unit areas is $76,800,000. Factored total construction cost is approximately $195,000,000.

Estimated total fixed capital investment is $270 million, including total construction costs, home office engineering, escalation, and sales taxes.

In addition to the fixed capital investment, other costs are those of land acquisition, rights-of-way, water and mineral rights, and startup. These items are estimated to total approximately $40 million, as shown in Table 6.

Estimated total capital requirement for the project, including fixed capital investment, startup costs, and recommended working capital, amounts to about $310 million. This total is exclusive of interest burden during construction, which depends on the financing method selected.

Procedures

The demonstration plant fixed capital investment is a preliminary cost estimate for the engineering, design, procurement, and construction of facilities to process 10,000 tons of Illinois No. 6 seam coal to produce low-sulfur boiler fuels. The estimate is considered to be within the -5 to +20% accuracy range as of late 1973. It includes costs of process equipment, construction materials, field labor, field indirect costs, engineering, design and drafting, project management, procurement, supporting services and reasonable price escalation. Allowances for instrument checkout and mechanical run-in are also included.

The project is divided into unit areas, as shown in Table 7.

Major process equipment costs were based on preliminary vendor pricing and historical Parsons data. Vendor prices were obtained for some special process equipment where in-house pricing data were not completely applicable.

In the case of direct materials, labor, and other costs, estimates for concrete, structural steel, piping, instrumentation, and electrical totals for various unit areas were made by factoring with a multiplier. The factoring method relies on previous job experience for similar process functions. The multiplier is determined by using the ratio of construction costs to major equipment costs.

Labor costs included reflect current average hourly rates for southern Illinois and expected labor productivity for that area.

The estimate is based on the work being performed during a regular work week defined as five eight-hour days, Monday through Friday.

No provision for premium costs for scheduled overtime work is included. However, an allowance for limited nonscheduled overtime is included in the estimating methods employed.

Engineering-construction home office costs were based on management and administration, process and project engineering, construction support, design, drafting, accounting, estimating, scheduling, cost engineering, procurement, expediting, inspection, stenographic, clerical, engineering construction fee, overhead, and out-of-pocket expenses such as printing, reproduction, computer charges, communications and travel.

Illinois 4 percent sales tax and/or use tax was included for material and equipment.

The estimate is based on total project duration of 48 months with an assumed start of engineering on January 1, 1974 and construction start on about April 1, 1975. Estimated completion and plant startup is late 1977.

Escalation has been applied for the specific duration of the project to expected costs of equipment, materials, and labor.

No contingency allowance has been applied to this -5 to +20% preliminary estimate.

PROJECT SCHEDULE

The project schedule shown in Figure 6 indicates that, for a total contract award by January 1, 1974, the demonstration scale plant can be designed and engineered, equipment procured and installed, and the plant mechanically complete by the end of calendar year 1977. Plant commissioning and startup would continue into 1978, with partial plant production during 1978.

The schedule assumes that all phases of project execution, process design, engineering, procurement, and construction responsibilities are released to a single major contracting firm.

It is estimated that allocation of the project into separate engineering and construction responsibilities divided between more than one subcontractor would extend the overall project completion date to about mid-1978 for plant startup.

FUND EXPENDITURE SCHEDULE

The estimated rate of project expenditures by semiannual periods is presented in Figure 7. Cumulative expenditures are shown in Figure 8. The fund requirement schedule, as shown, does not include interest charges on the estimated fixed capital investment of $270 million.

The schedule of expenditures reflects the rates of spending as the project moves from conceptual engineering through detailed mechanical engineering, procurement, and construction phases based upon the project schedule (Figure 6).

PRELIMINARY CONCLUSIONS

While considerable data are available on coal liquefaction, the specific conditions of recycle of unfiltered dissolver product to form feed coal slurry are based upon relatively scant data. Therefore, additional work is needed to confirm design yields and assure process feasibility. The basis used for this design is essentially that established by the process development contractor. Critical parameters were:

(1) Recycling of unfiltered liquid effluent from the dissolvers.

(2) Hydrogen consumption for the dissolving section at 3 weight percent of the coal feed.

(3) Residence time for liquid in the preheater and dissolver at one hour.

(4) Use of syngas (hydrogen plus carbon monoxide) to supply hydrogen requirements of dissolving.

(5) Conversion, solid to liquid, of coal in the dissolver at 91 percent.

(6) Filtration of net dissolver product to remove undissolved solids from the product. Filter cake to contain equal weights of undissolved solid and liquid product.

(7) Preheater outlet and dissolver temperatures at 900°F and 840°F, respectively.

(8) Solvent recycle rate at twice coal-feed weight.

Limited laboratory results indicate that the use of unfiltered solvent is attractive for both yield and character of liquid product from coal. The demonstration plant is designed on this basis. As a consequence of the recycle of undissolved material, the resultant product boils at lower temperatures, is liquid at ambient temperatures, and is lower in sulfur content than if the recycle solvent were free of solids. A result of use of this scheme, vis-a-vis use of filtered recycle feed to the dissolver, is that hydrogen input to the coal is higher, which tends to lower the plant's thermal efficiency.

Additional data should be developed to define residence time required to achieve coal liquefaction. It is logical that residence time could be reduced if higher temperatures and possibly higher pressures were employed at the dissolvers. Sufficient data should be obtained to accurately establish the relationship between temperature and residence time.

It is most critical that experiments be made to achieve equilibrium with regard to recycle liquid composition and quantity. Since predictions of yield, product quality, and ease of filtration are dependent upon accurate laboratory results, more laboratory or pilot plant work is required in this area.

More data are needed in cases where equilibrium recycle liquid composition is attained with hydrogen gas and then syngas. It would be valuable to extend these data to include effects of higher temperatures and shorter residence times since liquefaction is expensive. Specifically, future laboratory experiments should demonstrate effects of pressure and gas rate on conversion.

Gasification unit design is principally based upon suspension flow technology modified to maximize syngas production. Heat considerations that are a direct result of the mechanical design of the gasifier must be resolved. Heat loss value used in the design prepared for this paper is 270 Btu per pound of coal equivalent. Reported values from the various sources range from a heat loss of 55 to 1,200 Btu per pound of coal. With higher heat loss, more oxygen is required and, consequently, more carbon dioxide is produced. This question needs to be resolved before finalizing gasifier design and that of supporting facilities.

The amount of liquid that must be carried with the filter cake to make it pumpable and injectable into the gasifier should be researched. Laboratory experiments should be conducted using mixtures of dry filter cake and filtrate at near pumping temperatures to determine physical properties and flow and injection characteristics of the material.

General conditions for desulfurization units were taken from data on COED oil. The severity of desulfurization and the feed stock are less demanding in this design than would be the case for full-range COED oil. The technology for this process is generally known, but specific conditions for this stock are not precisely known. To assure reliability and performance of such a unit, actual feed stock for the unit should be derived from pilot plant operation and made available for at least bench-scale tests on the catalyst to be used. Specifically, laboratory testing should be conducted to determine to what extent organometallic compounds are present in the feed, and in what boiling range of the feed these materials exist.

No provision has been made in this design for the presence of organometallic compounds and their detrimental effect on catalyst performance and life, because the material desulfurized in this design boils below the temperature at which these compounds would be expected to appear in petroleum-derived liquids.

The detailed design of the proposed demonstration plant would be in progress while the pilot plant at Tacoma is in operation. It is possible that many of the operating and quality questions can be answered and/or demonstrated by the performance of Tacoma. We hope that the schedule of the Tacoma pilot plant can be adjusted to complement the demonstration plant design.

During the course of the design assignment, analysis showed that it is possible to achieve the production of desulfurized liquid fuels exclusively when using an alternative approach to syngas production. The current preliminary design employs gasification of a coal residue from the liquefaction plant for this purpose. One alternative is to use the offgases from the liquefaction plant for syngas production rather than for plant fuel. The coal residue could then be gasified, possibly with air, for production of desulfurized low-Btu fuel gas for captive use. Heating values produced by this scheme can be absorbed in the total plant design without introducing a fuel imbalance.

The design criteria did not permit purchase of hydrocarbon feedstocks for plant start-up. Also, the plan is to include demonstration of syngas production by gasification of coal or a coal-sourced solid in the design. These objectives could be achieved using the plant modification for syngas described above. With this modification, the gasification operation is removed from the main production line and becomes a service plant producing fuel gas at low pressure. Such a service plant can be designed with as many parallel trains needed to support a desired design service factor.

TABLE 1 - DEMONSTRATION PLANT PRODUCTS

Product	Characteristic	Value
Liquid (4 billion Btu/hr; sulfur content, 0.5% max.)	Flash point Higher heating value °API	150°F 16,660 Btu/lb -9.7 60/60°F
Hydrogenated Liquid (2 billion Btu/hr; sulfur content, 0.2% max.)	Flash point Boiling range Higher heating range °API	150°F 400-870°F 18,330 Btu/lb 13.9 60/60°F
Hydrogenated light oil	Boiling range Gravity Nitrogen Sulfur	C_4-400°F 52° API 5 ppm 1 ppm
Ash	-	-
Sulfur	Purity	99.5% (min.)

TABLE 2 - DEMONSTRATION PLANT RAW MATERIALS

Illinois No. 6 seam coal with the following typical analysis:

Proximate analysis

Constituent	Amount
Moisture	2.70 weight percent
Ash	7.13 weight percent
Volatile matter	38.47 weight percent
Fixed carbon	51.70 weight percent
Heating value	12,821 Btu/lb

Ultimate analysis

Element	Weight Percent
Carbon	70.75
Hydrogen	4.69
Nitrogen	1.07
Sulfur	3.38
Oxygen	10.28

Oxygen, 99.5%; produced within battery limits

River water

TABLE 3 - EXAMPLE OF EQUIPMENT LIST

ITEM NO.	DESCRIPTION	SIZE	PRESS/TEMP°F PSIG	MATERIAL/REMARKS
UNIT 11 - COAL SLURRYING AND PUMPING				
11-1201	Slurry Mix Vessel	18'-0" I.D. x 27'-0"	17/425	SA-285C
11-1202	Slurry Vapor Condensate Drum	5'-0" I.D. x 15'-0"	16/125	SA-285C
11-1203	Slurry Holding Tank	18'-0" I.D. x 27'-0"	17/425	SA-285C
11-1301	Slurry Vapor Condensate	29.9 MMBTU/Hr.	16/446	C.S Shell & Tube
11-1501	Slurry Recirculation Pump	9,000 GPM	35/446	20 Chr. Stl.
11-1551	Slurry Recirculation Pump Spare	9,000 GPM	35/446	20 Chr. Stl.
11-1801	Slurry Vapor Blower	21 SCFM	35/100	C.S. W/C.I. Impeller
11-2001 thru 06	Screw Feeders	16" I.D. x 10'	Link Belt Type C, 5 HP ea.	
11-2401	Agitator/11-1201		Chemineer, Model 8HTA30, 30 HP ea.	
11-2402	Agitator/11-1203			
UNIT 12 - COAL LIQUEFACTION AND FILTRATION				
12-1201	High Pressure Primary Separator	8'-6" I.D. x 17'-0"	1240/840	1-1/4 Cr, 1/2 Mo. Stl.
12-1207	High Pressure Intermediate Flash Drum	12'-0" I.D. x 24'-0"	1220/370	SA-515-70, 1/8 C.A.
12-1208	High Pressure Condensate Flash Drum	13'-0" I.D. x 36'-0"	1175/125	SA-515-70, 1/8 C.A.
12-1209	High Pressure Condensate Surge Drum	9'-0" I.D. x 15'-0"	1175/125	SA-515-70, 1/8 C.A.
12-1210	Intermediate Pressure Liquid Flash Drum	11'-0" I.D. x 22'-0"	500/575	SA-515-70, 1/8 C.A.
12-1211	Intermediate Pressure Vapor Flash Drum	5'-6" I.D. x 16'-0"	495/125	SA-515-70, 1/8 C.A.
12-1212	Low Pressure Liquid Flash Drum	15'-0" I.D. x 30'-0"	150/575	SA-515-70, 1/8 C.A.
12-1213	Filtrate Flash Drum	16'-0" I.D. x 20'-0"	110/575	SA-515-70, 1/8 C.A.
12-1214	Filtrate Vapor Flash Drum	15'-0" I.D. x 20'-0"	105/125	SA-515-70, 1/8 C.A.
12-1215	Solvent Flash Drum	12'-0" I.D. x 24'-0"	16/570	SA-385C
12-1216	Solvent Vapor Flash Drum	5'-0" I.D. x 15'-0"	21/125	SA-385C
12-1217	Water Surge Drum	5'-0" I.D. x 12'-0"	350/125	SA-515-70
12-1218	Make Up Gas 1st Stage Condensate Drum	10'-0" I.D. x 12'-0"	375/125	SA-515-70
12-1219	Make Up Gas 2nd Stage Condensate Drum	7'-6" I.D. x 12'-0"	735/125	SA-515-70
12-1220	Solvent Vapor 1st Stage Condensate Drum	3'-0" I.D. x 8'-0"	27/125	SA-385C
12-1221	Solvent Vapor 2nd Stage Condensate Drum	3'-0" I.D. x 8'-0"	116/125	SA-385C
12-1222	Precoat Slurry Vessel	12'-0" I.D. x 22'-0"	32/518	SA-385C
12-1223	Filter Drain Vessel	5'-0" I.D. x 10'-0"	550/300	SA-515-70

TABLE 4 - EXAMPLE UNIT COST TABULATION

Account Code	Description	Coal Preparation Unit 10 Materials and Expense	Coal Slurrying and Pumping Unit 11 Materials and Expense	Coal Liquefaction and Filtration Unit 12 Materials and Expense	Dissolver Acid Gas Removal Unit 13 Materials and Expense	Coal Liquefaction and Product Distillation Unit 14 Materials and Expense	Fuel Oil Hydro-genation Unit 15 Materials and Expense	Naphtha Hydro-genation Unit 16 Materials and Expense	Fuel Gas Sulfur Removal Unit 17 Materials and Expense
1100	Columns				2,550,000	159,000	29,000	22,000	126,000
1200	Vessels		126,000	3,290,000	192,000	18,000	2,312,000	116,000	16,000
1300	Heat Exchangers and Condensers		22,000	2,995,000	1,284,000	142,000	1,105,000	165,000	184,000
1400	Furnaces, Heaters			4,900,000		226,000	182,000	71,000	
1500	Pumps and Drivers		41,000	2,008,000	603,000	42,000	197,000	39,000	94,000
1600	Boilers								
1700	Cooling Towers								
1800	Compressors and Blowers		1,000	2,435,000			1,270,000	95,000	
1900	Storage Tanks			62,000	157,000				10,000
2000	Materials Han-dling Equipment		9,000	44,000					
2200	Separation Equipment				45,000				
2300	Package Plants	3,100,000							
2400	Agitators, Mixers and Blenders		10,000	4,000					
2500	Reactors (All Types)			4,740,000					
2800	Other Major Equipment			1,200,000	117,000				45,000
	Total Major Equipment Cost	3,100,000	209,000	21,678,000	4,948,000	587,000	5,095,000	508,000	488,000

TABLE 5 - PRELIMINARY FIXED CAPITAL INVESTMENT SUMMARY

Unit	Description	Major Equipment Costs ($)
10	Coal Preparation	3,100,000[a]
11	Coal Slurrying and Pumping	209,000
12	Coal Liquefaction and Filtration	21,678,000
13	Dissolver Acid Gas Removal	4,948,000
14	Coal Liquefaction Product Distillation	587,000
15	Fuel Oil Hydrogenation	5,095,000
16	Naphtha Hydrogenation	508,000
17	Fuel Gas Sulfur Removal	488,000
18	Gasification	4,188,000
19	Acid Gas Removal	1,416,000
20	Shift Conversion	1,337,000
21	CO_2 Removal	615,000
22	Methanation	102,000
23	Sulfur Plant	1,941,000
24	Oxygen Plant	12,400,000[a]
30	Instrument and Plant Air	172,000
31	Raw Water Treatment	2,481,000
32	Process Waste Water Treatment	380,000
33	Power Generation	10,430,000
35	Product Storage	2,231,000
36	Slag Removal System	30,000
37	Steam Generation	1,512,000
40	General Facilities	950,000
	Total	76,798,000
	Total Construction Cost	194,700,000
	Home Office Engineering	27,600,000
	Escalation	43,700,000
	Sales Tax	4,000,000
	Fixed Capital Investment	270,000,000

[a]Package Plants (including foundations, piping, etc.)

TABLE 6 - ADDITIONAL CAPITAL COST INVESTMENT ITEMS

Item	Value (million $)
Initial Raw Materials, Catalysts, and Chemicals	1
Startup Costs	16
Initial Working Capital	22
Land Acquisition, Rights-of-Way, Mineral and Water Rights	1
Total	40

TABLE 7 - DEMONSTRATION PLANT UNIT AREA DESIGNATIONS

Unit Area	Facility
10	Coal Preparation (stockpiling, drying, grinding)
11	Coal Slurrying and Pumping
12	Coal Liquefaction and Filtration
13	Dissolver Acid Gas Removal
14	Coal Liquefaction Product Distillation
15	Fuel Oil Hydrogenation
16	Naphtha Hydrogenation
17	Fuel Gas Sulfur Removal
18	Gasification (gasifier and associated equipment)
19	Acid Gas Removal
20	Shift Conversion
21	CO_2 Removal
22	Methanation
23	Sulfur Plant
24	Oxygen Plant
30	Instrument and Plant Air
31	Raw Water Treatment (including cooling tower and boiler feedwater facilities)
32	Process Waste Water Treatment
33	Power Generation
35	Product Storage
36	Slag Removal System
37	Steam Generation
40	General Facilities - On-site

ARTIST'S CONCEPT - DEMONSTRATION PLANT

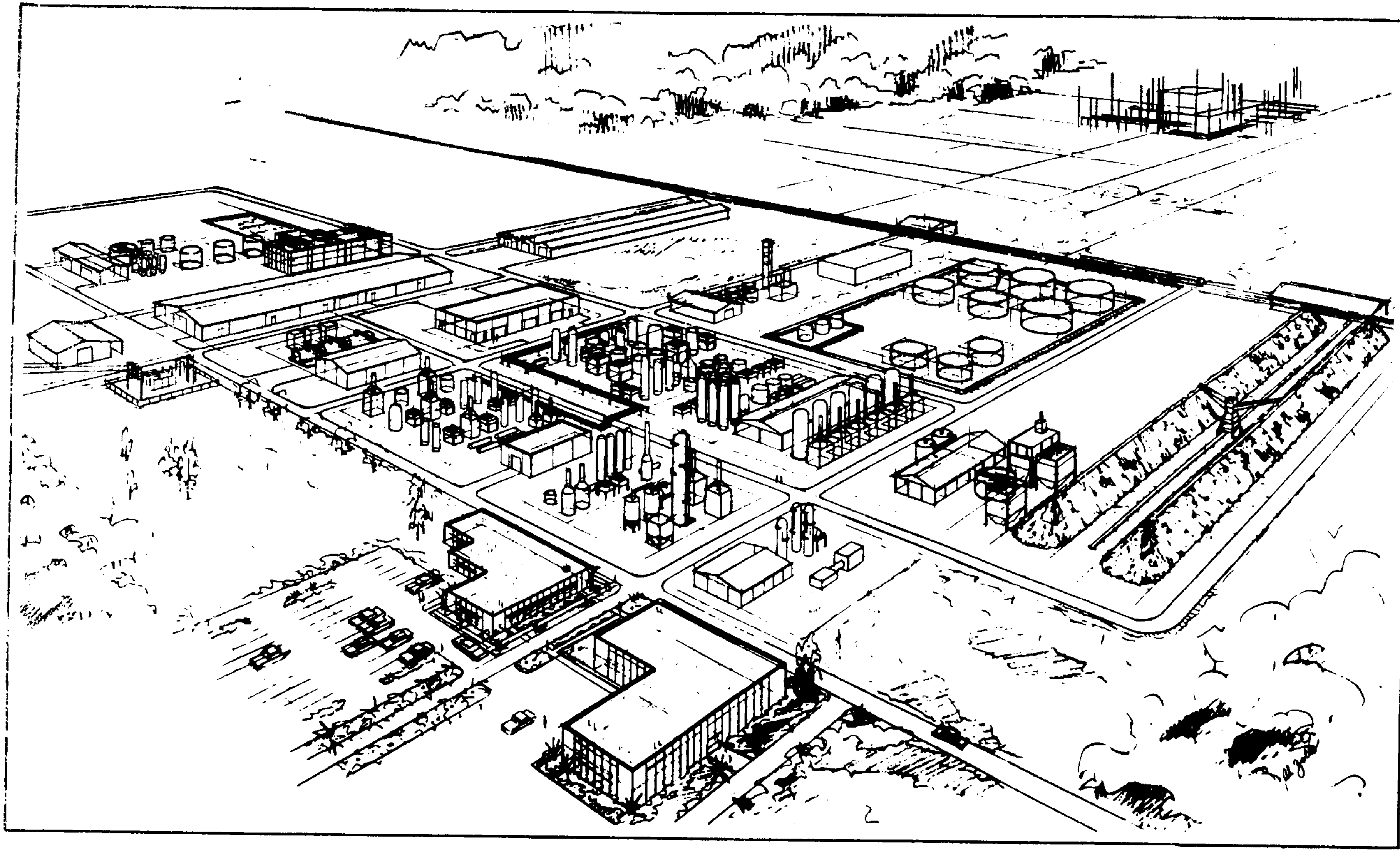


Figure 1 - Artist's Concept of Demonstration Plant

DEMONSTRATION PLANT
BLOCK FLOW DIAGRAM

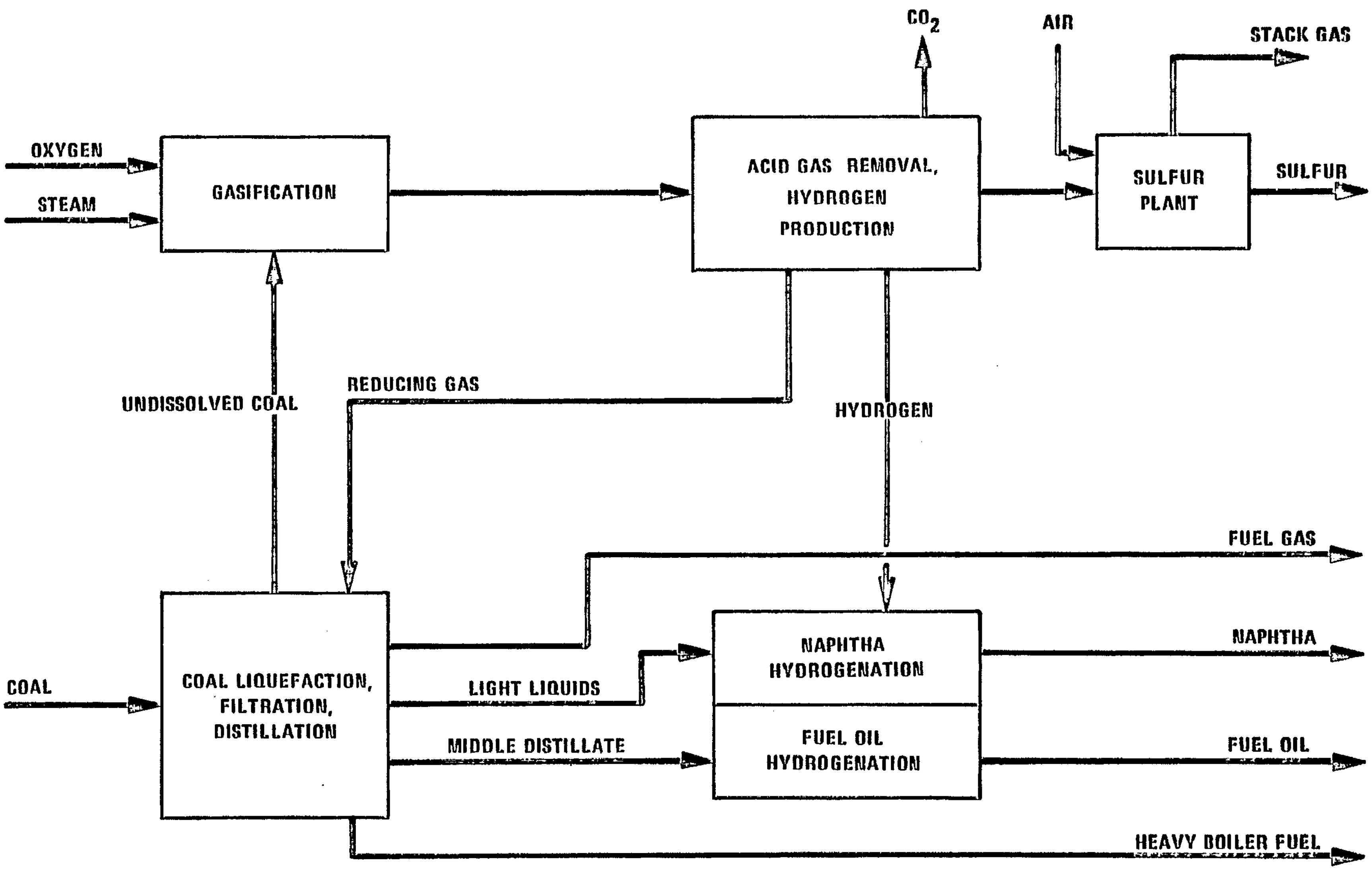


Figure 2 - Block Flow Diagram

DEMONSTRATION PLANT
OVERALL MATERIAL BALANCE

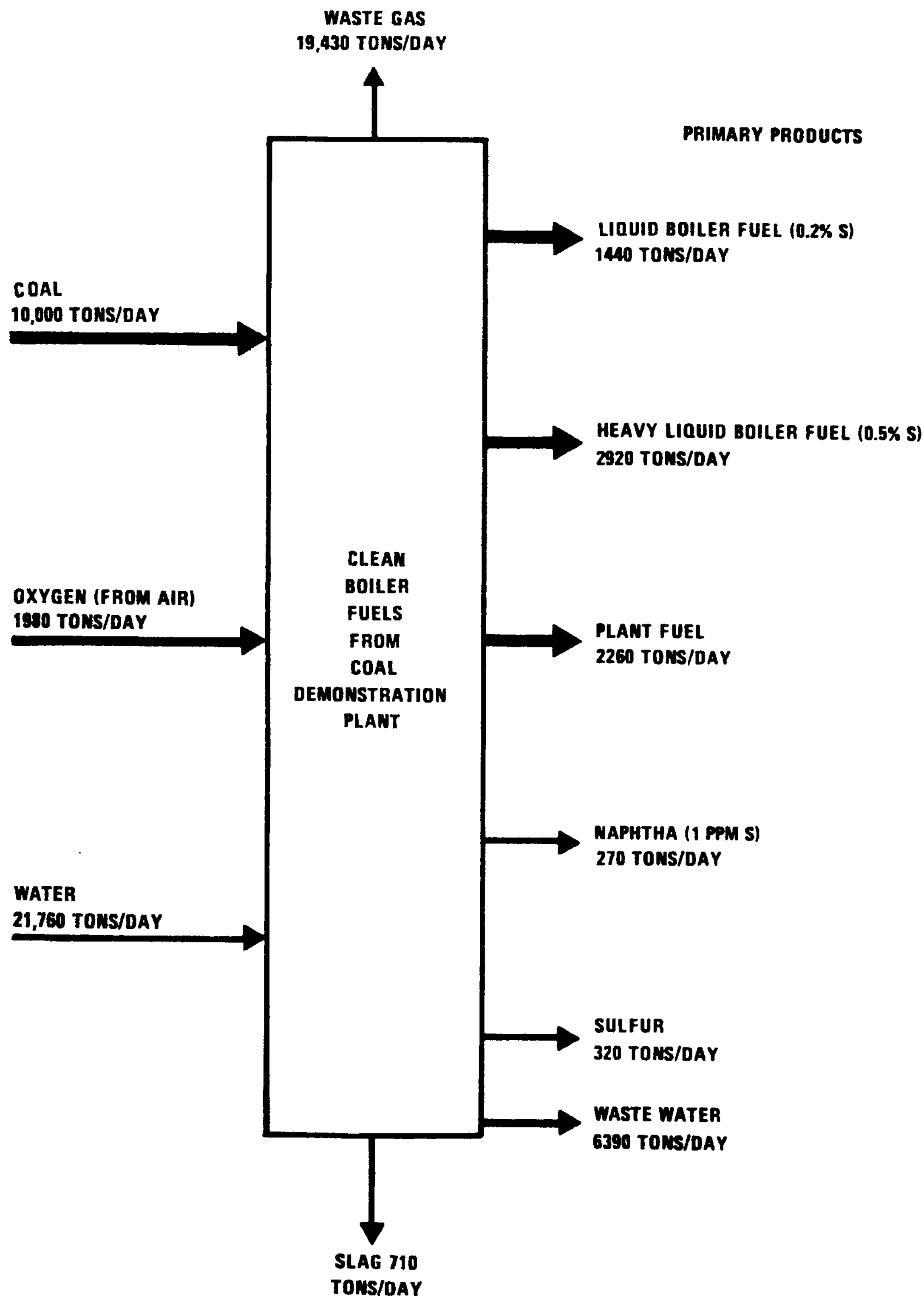
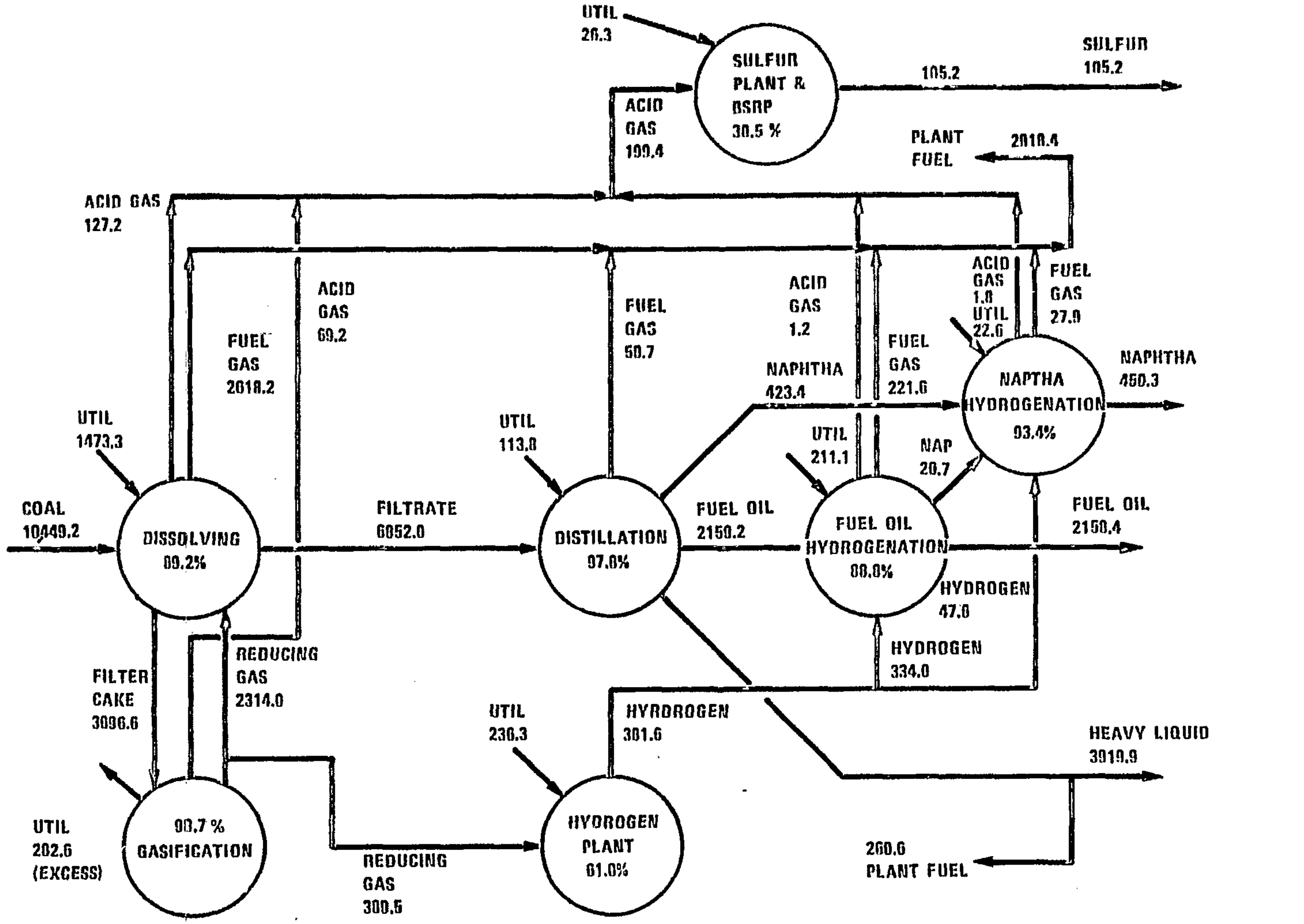


Figure 3 - Overall Material Balance



NOTE – LINE FIGURES ARE MM BTU/HR (GROSS)
– FIGURES IN CIRCLES ARE THERMAL EFFICIENCIES OF UNITS

$$\text{OVERALL EFFICIENCY} = \frac{105.2 + 450.3 + 2160.4 + 3919.9}{10449.2} = 63.5\%$$

Figure 4 - Detailed Energy Balance

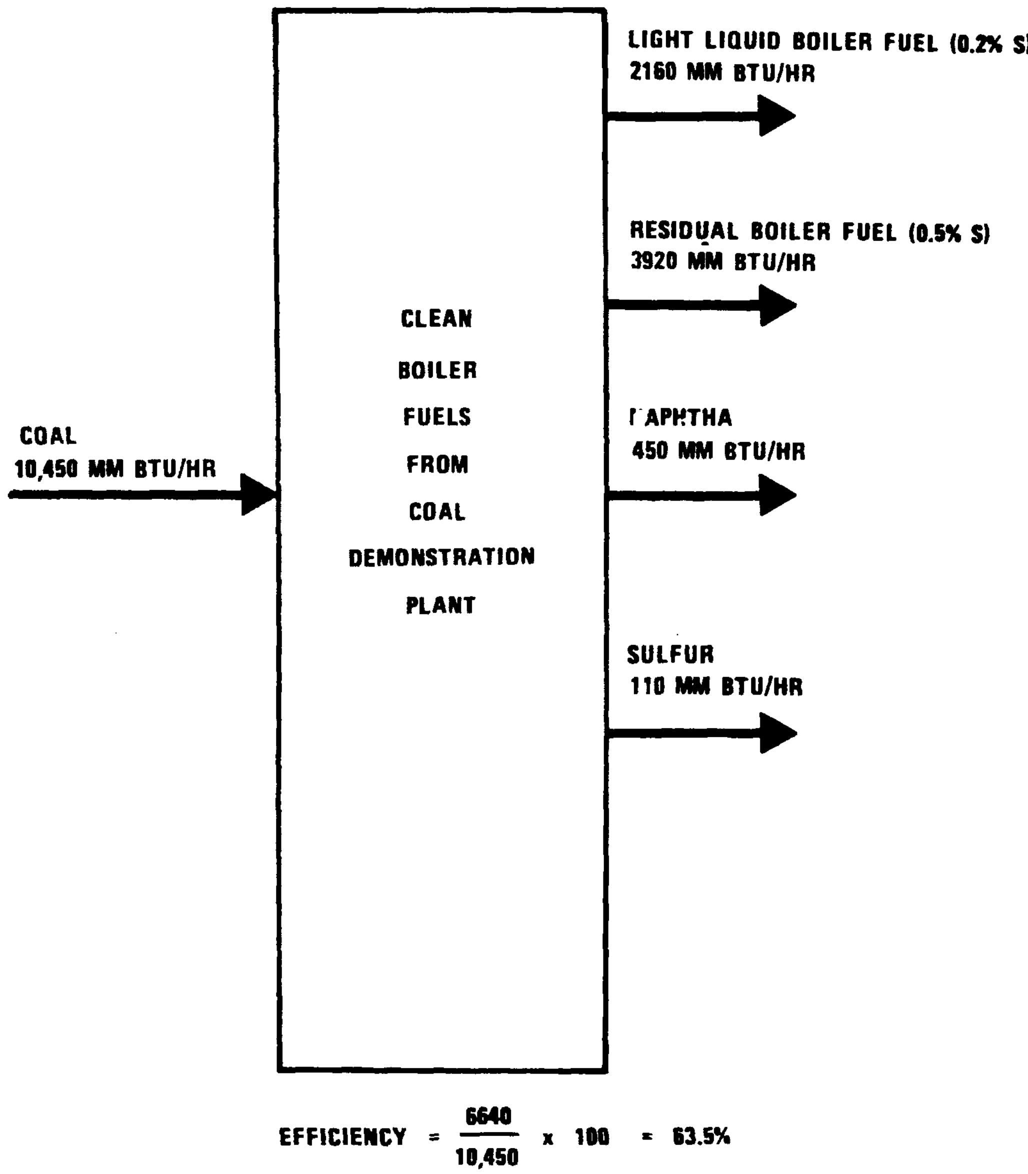


Figure 5 - Overall Energy Balance

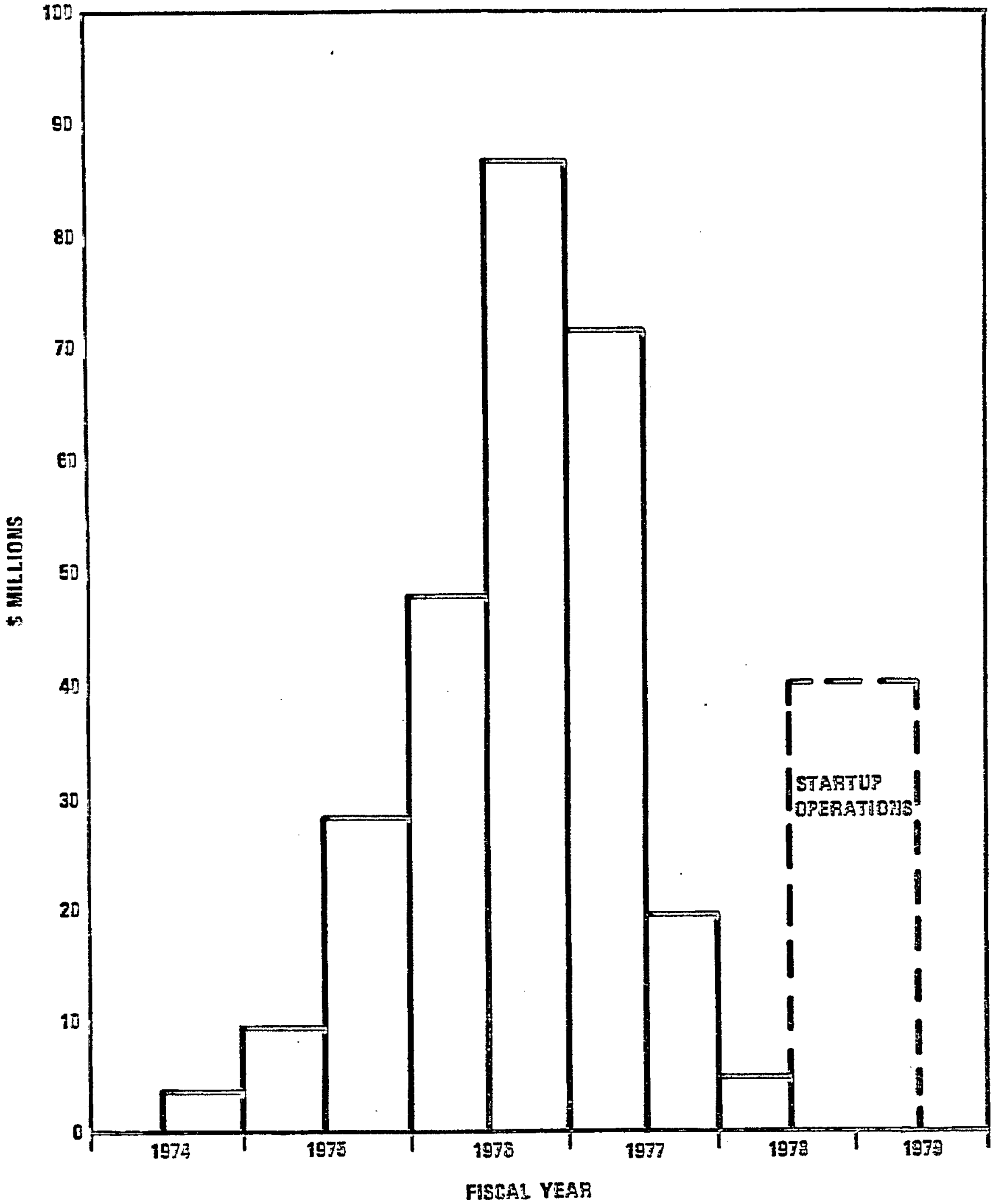


Figure 6 - Fund Drawdown Schedule (Semiannual Basis)

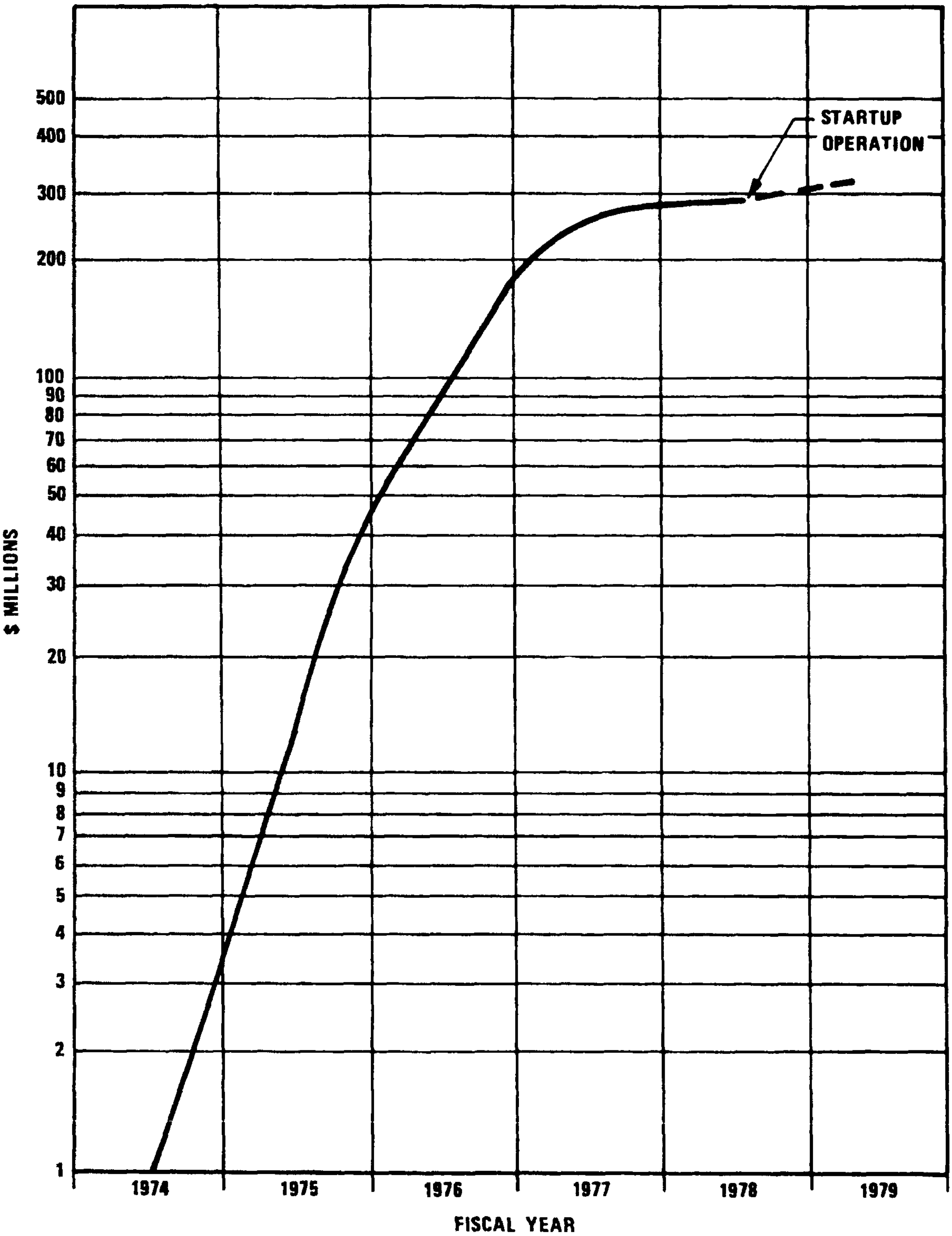


Figure 7 - Fund Drawdown Schedule (Cumulative Basis)

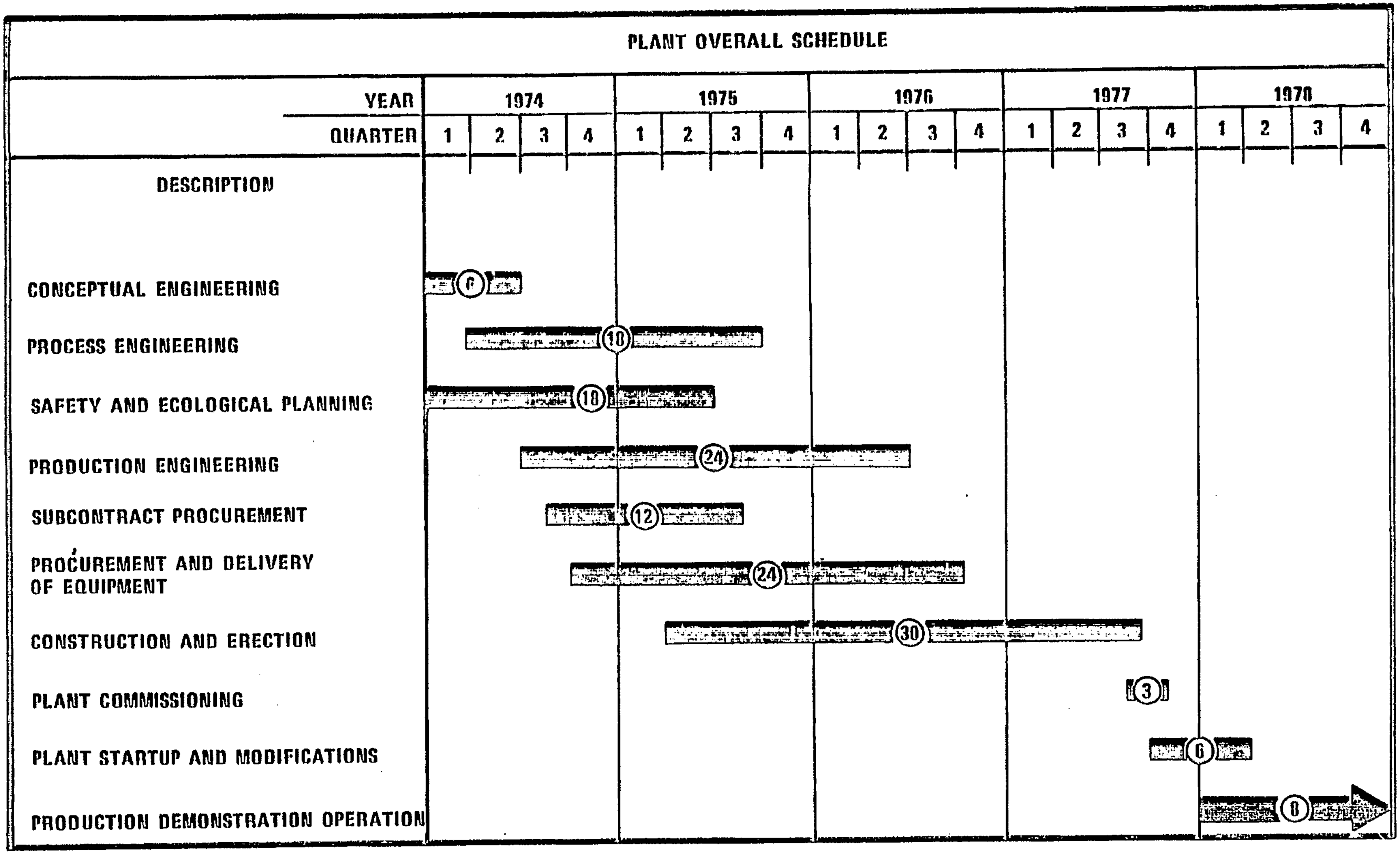


Figure 8 - Plant Overall Schedule

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COLLECTED WORK NO. 10

CLEAN BOILER FUELS FROM COAL

J.B. O'Hara, N.E. Jentz, S.N. Rippee and E.A. Mills
The Ralph M. Parsons Company
Pasadena, California

From "COAL PROCESSING TECHNOLOGY" — Volume 1

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CHEMICAL ENGINEERING PROGRESS

June 1974

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Clean Boiler Fuels from Coal

Here's a complete detailed preliminary design for a demonstration plant to produce low-sulfur liquid fuels from 10,000 tons per day of coal.

J.B. O'Hara, N.E. Jentz, S.N. Rippee, and E.A. Mills
The Ralph M. Parsons Co., Los Angeles, Calif.

A study summarizing the preliminary design and estimated capital investment for a demonstration-scale plant to produce clean boiler fuels from coal, has been completed by the Ralph M. Parsons Co. at the request of the Office of Coal Research (OCR).

Objectives of the preliminary design work were:

1. To establish a demonstration plant design to effectively produce clean boiler fuels from coal.
2. To estimate the fixed capital investment required for design, engineering, procurement, and construction of the coal conversion complex.
3. To estimate the earliest date when the coal conversion plant could be mechanically complete and ready to begin production.
4. To estimate the budgeting of funds to be expended during each semi-annual period over the life of the project.

The process design bases and yields for this plant were provided by OCR process development contractors, based on the OCR process design concept adjudged to have the greatest potential for converting a typical coal entirely into desulfurized liquid fuels.

On the basis of information provided by other OCR contractors, a preliminary design was developed as the first step in a development program to bring coal conversion processes to commercial reality. The design represents substantial engineering research, both for selection of equipment required and for processing techniques to achieve project objectives. This approach is consistent with OCR's philosophy of accepting potential risks in plant performance and cost uncertainty in order to speed the development of viable commercial designs. It should be recognized that this preliminary design is based on immature technology and precedes the availability of experimental results from pilot-plant operations for the two primary coal conversion steps of liquefaction and production of synthesis gas (syngas) by the proposed mode of gasification.

Demonstration plant objectives

Objectives of the demonstration plant facility were conceived to be:

1. To speed commercialization of coal conversion processes for production of "clean" fuels from indigenous high sulfur coals.
2. To leapfrog the pilot-plant program to gain time in the development of commercially viable coal conversion processes.
3. To provide adequate liquid fuels for prolonged testing in commercial power plant operations.
4. To define performance requirements and financial incentive for prompt development of hardware required for large-scale coal conversion plants for testing in demonstration plant facilities.
5. To demonstrate the operability of commercial scale coal conversion equipment.
6. To provide a basis for accurately predicting the economics of commercial scale coal conversion plants.
7. Following demonstration plant operation, to permit simultaneous design of multiple commercial coal conversion plants.

The design basis for the clean boiler fuel manufacturing facility to process 10,000 ton/day of coal is a grass-roots complex in southern Illinois with all coal handling facilities, process units, and necessary supporting facilities to serve the needs of administrative, operating, maintenance, development, and service personnel. An artist's concept of the facility is shown in Figure 1. Products and raw materials are given in Table 1.

The plant will contain two primary process units: a modified Solvent Refined Coal (SRC) unit, and a gasifier to produce syngas. The latter is being modified from a process under development. It has the following two characteristics: a) capacity adequate to supply reducing gases for the SRC dissolver, SRC liquefied coal hydrogenation, and light oil hydrogenation; and b) feed to the gasifier unit, consisting of equal weights of dry filter cake from the SRC unit and filtrate.

Phenolics/cresylics will be recycled to extinction by returning that stream to the light oil hydrogenator. A fixed-bed hydrogenator will be used on the SRC distillate.

All effluent streams will be treated to meet applicable environmental standards. Solid disposal will be integrated with coal delivery to provide haul-away and proper disposal. Equipment will be designed to meet OSHA noise level requirements.

Inventories will be maintained as follows: coal, 3 days; and products, 30 days.

Three major sections in the complex

The process configuration is depicted in the block process flow diagram, seen in Figure 2. The complex is described under three major headings: coal preparation, a coal liquefaction section, and a gasification section.

The complex is designed to charge 10,000 ton/day of coal and to produce two low-sulfur liquid fuel streams as its major products. The two forms of fuel will consist of a liquid product containing approximately 0.5 wt.-% sulfur, sufficient to fuel a 400-mw power plant—and a desulfurized distillate fuel oil product containing 0.2 wt.-% sulfur,

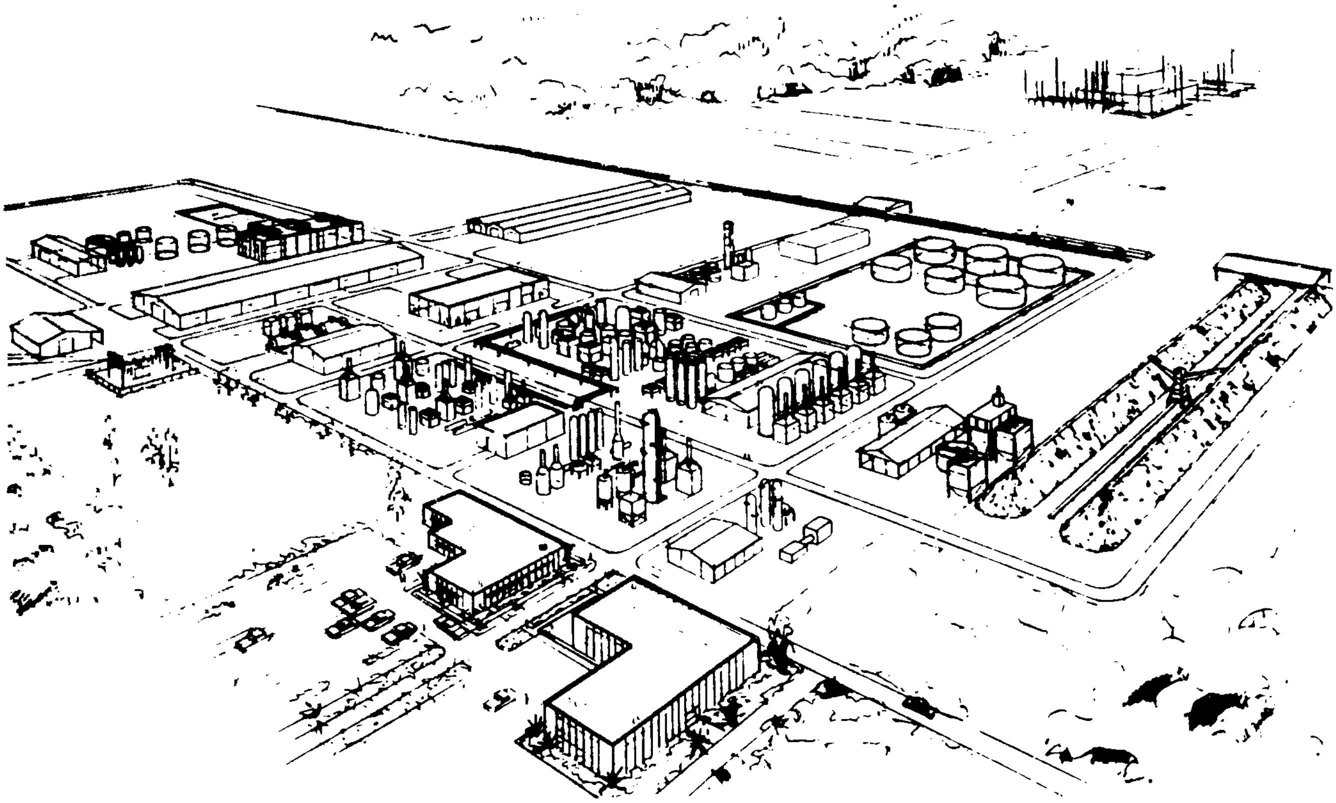

Figure 1. Artist's conception of demonstration plant.

Table 1. Demonstration plant raw materials and products

Raw materials

1. Illinois No. 6 seam coal (typical analysis):

Proximate analysis:	
Moisture, wt.-%	2.70
Ash, wt.-%	7.13
Volatile matter, wt.-%	38.47
Fixed carbon, wt.-%	51.70
Heating value, Btu./lb.	12,821
Ultimate analysis (wt.-%):	
Carbon	70.75
Hydrogen	4.69
Nitrogen	1.07
Sulfur	3.38
Oxygen	10.28

2. Oxygen (99.5%), produced within the battery limits
3. River water

Products

1. Two primary boiler fuels:
   a. 4,000 million Btu./hr. (minimum) liquid, with a maximum 0.5% sulfur, and

Flash point, °F	150
Higher heating value, Btu./lb.	16,660
Specific gravity, °API, 60/60 °F.	−9.7

   b. 2,000 million Btu./hr. (minimum) of hydrogenated liquid, with a maximum 0.2% sulfur, and

Flash point, °F	150
Boiling range, °F	400 to 870
Higher heating value, Btu./lb.	18,330
Specific gravity, °API, 60/60 °F.	13.9

2. Hydrogenated light oils, with the following approximate characteristics:

Boiling range	C_4 – 400°F.
Specific gravity, °API	52
Nitrogen, ppm.	5
Sulfur, ppm.	1

3. Ash:
4. Sulfur of 99.5% minimum purity.

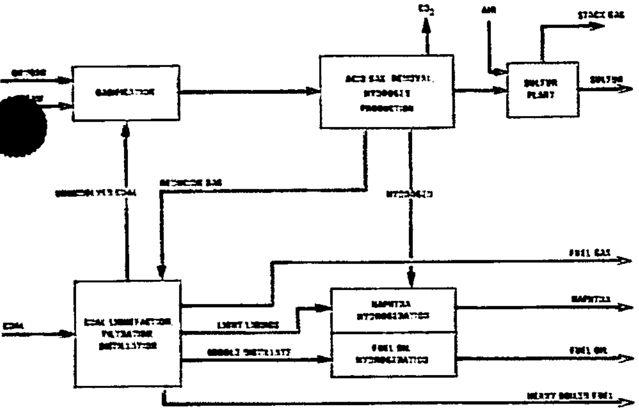

Figure 2. Demonstration plant block flow diagram.

sufficient to fuel a 200-mw power plant. By-products are hydrotreated naphtha and sulfur recovered from the various desulfurizing processes. The light hydrocarbons produced are burned for plant fuel.

In the case of an alternate product objective, the plant could convert the gas streams to produce approximately 67 million cu.ft./day of synthetic natural gas (SNG). In this case, a portion of the liquid fuels produced would be consumed for in-plant energy needs.

The SRC process is being developed to produce low-sulfur, de-ashed fuels from coal. Data and experience from this work have been used as background for this design. The "Bi-Gas" gasification process also is being developed under contract to the Office of Coal Research. Data from this work and other sources have been used in this design. The gasification process will convert wet filter cake from the liquefaction section to reducing gas required for operation of the liquefaction process.

Run-of-mine coal will be purchased and received at a rate of 12,500 ton/day. The complex will store and prepare it for feed to the process units in the following way. A rail car dumper empties each car into a hopper below rail level. This hopper can also receive coal from mine trucks. A vibrating feeder moves the coal onto a belt conveyor that transfers it to a rail-mounted slewing stacker, which places it in storage. The stockpile will hold 37,500 tons of coal, a 3-day inventory. Compactors have been provided for the stockpile.

Reclaiming is by a bucket-wheel, mounted on tires, feeding a transverse conveyor to one of the two reclaim belt conveyors. A transverse conveyor takes the coal from either of the reclaim conveyors and delivers it to the coal preparation plant for washing. The stockpiling system will handle 900 ton/hr. of coal, and the reclaim system 800 ton/hr.

Coal preparation, drying, and grinding

Coal of about 10% moisture is conveyed from the stockpile to a 300-ton bin. A 60-in. reciprocating plate feeder removes coal from the bin and places it on a 48-in. belt conveyor fitted with a tramp iron magnet, which feeds an 8 by 20 ft. scalping screen. The 3-in.-plus coal is fed to a rotary coal breaker. Oversize refuse from the breaker is returned to the mine for burial. The broken coal (3-in.-minus) is placed on a 48-in. belt conveyor where it is combined with the undersize coal from the screen and dumped into an 8,000-ton storage pile.

Coal from the storage pile is conveyed to the washing plant where a series of jigs, screens, centrifuges, cyclones, and a roll crusher clean and reduce it to minus 1¼-in. Refuse from this operation is also returned to the mine area for disposal. Wet fine refuse is pumped to settling ponds.

The clean, 1¼-in.-minus coal is then dried in a flow dryer and reduced to 1/8-in.-minus in two pulverizers for dissolver feed. To prepare the feed to the SRC unit, the dried, ground coal is transferred by conveyor to the coal solvent slurry tank; 10,000 tons of coal and 20,000 tons of recycle solvent per day are metered into this tank. The slurry of 1/8-in.-minus coal in SRC solvent is pumped through a low-pressure loop which feeds high-pressure pumps; these pumps transfer the slurry to the dissolvers at pressures up to 1,000 lb./sq.in. Excess slurry in the loop is returned to the slurry tank.

The feed, containing 10,000 ton/day of 1/8-in.-minus coal as a 50-wt.-% slurry in a recycle solvent, is charged to a reactor where it is contacted with a reducing gas at about 185°F and 1,000 lb./sq.in.gauge. The mixture from this system consists of a liquid phase, a solid phase of ash plus undissolved coal, and a gas phase. The gas phase is separated and largely recycled after controlling the level of impurities. The solid phase is separated from a portion of the liquid phase by means of filtration and then transferred to the gasification plant where the residual carbonaceous material is gasified to produce syngas. The remainder of the unfiltered dissolver liquid product containing undissolved coal particles is used for recycle to slurry the feed coal.

Liquid phase filtrate is fractionated to a naphtha stream, a distillate which will be desulfurized to become light boiler fuel, and the residual fuel oil. The residual fuel oil will have a sulfur content of about 0.5 wt.-%. Enough residual will be produced to fuel a 400-mw power plant.

The distillate fraction of the coal liquefaction product is catalytically hydrogenated to produce a light fuel oil containing a maximum of 0.2% sulfur adequate to supply fuel for a 200-mw power plant.

Light liquid produced in the coal liquefaction process, plus naphtha formed during the SRC distillate hydrogenation step, are combined and hydrotreated to remove additional sulfur and nitrogen. The levels of nitrogen and sulfur in the product naphtha will be reduced to approximately 5 ppm. and 1 ppm. respectively. The composition and purity of this high-quality naphtha make it suitable for sale.

Sulfur is recovered from hydrogen sulfide

Gases produced in the various units are combined and fed to the acid gas removal plant where the carbon dioxide and hydrogen sulfide are removed. The hydrogen sulfide is converted to sulfur in the sulfur recovery unit, while the carbon dioxide is vented to the atmosphere. The sulfur plant includes a tail gas purification unit and produces effluent meeting all existing environmental restrictions. The "sweet" gases, following removal of carbon dioxide and hydrogen sulfide, are used as fuel within the plant.

Wet filter cake from the liquefaction process is fed to a slagging, suspension-type gasifier unit, where it meets steam and oxygen at 3,000°F and 200 lb./sq.in.gauge. The carbonaceous material is gasified and produces primarily synthesis gas (carbon monoxide and hydrogen). Oxygen required for operation of this unit is produced in the plant.

Synthesis gas product from the gasifier is passed through heat recovery boilers, course char cyclones, and a venturi scrubbing system. Solids containing carbon are reclaimed and recycled to the slagging section of the gasifier unit. The cooled syngas is then treated for carbon dioxide and hydrogen sulfide removal by adsorption in the acid gas removal system. The off-gas (H_2S) stream is sent to the sulfur plant for treatment and recovery of sulfur values.

Most of the purified gas effluent from the acid gas removal system is used directly as reducing gas in the coal liquefaction plant. Gas not sent directly to the liquefaction section is subjected to shift conversion, whereby carbon monoxide reacts with steam to produce hydrogen and carbon dioxide.

Gas from shift conversion is sent to a carbon dioxide removal step and a final methanation unit where residual carbon dioxide and carbon monoxide are converted to methane. The resulting hydrogen stream is then fed to the product distillate and naphtha hydrogenation unit. Slag, produced in the gasification unit, is solidifed and transported to a storage pile near the feed coal storage pile. Slag will be removed from the site as a back-haul item for the coal supply trains. The overall material balance is shown in Figure 3.

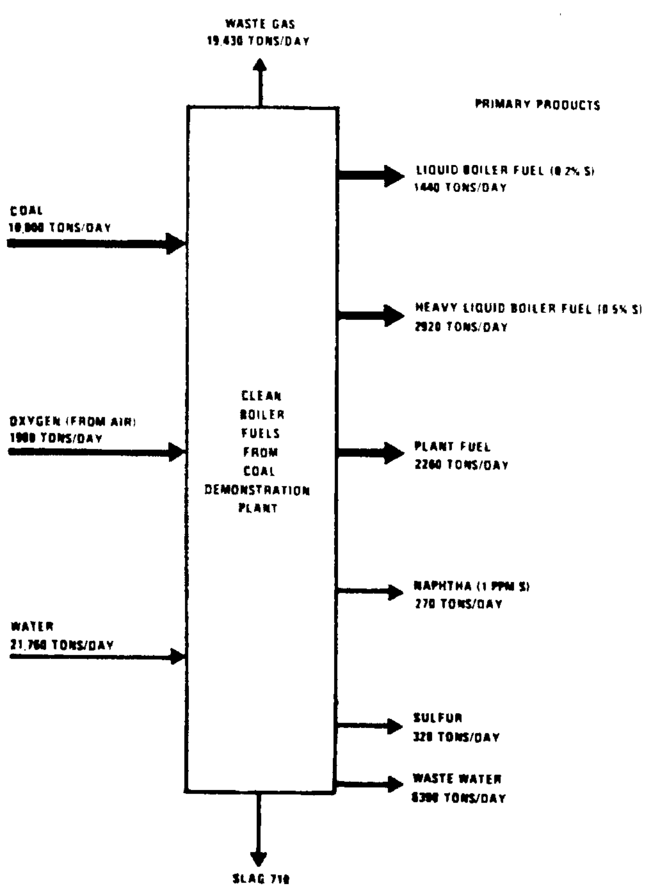

Figure 3. Overall material balance.

Overall thermal efficiency is good

Detailed analysis of the energy balances around the separate process units, and an overall energy balance are shown in Figures 4 and 5. Thermal efficiency of the demonstration plant is defined as gross heating value of all products, less utility duties, divided by the gross heating value of the feed coal. Figure 4 shows that unit efficiencies are generally high, except for the dissolver at 89.2% and the hydrogen purification units at 61.0%. Despite these high individual unit efficiencies, estimated overall thermal efficiency for this plant is 63.5%.

Stream calculations used in the design of the demonstration plant are based upon product yields and compositions supplied by OCR development contractors. Although most of the streams do balance, there is an inconsistency in elemental balances. To arrive at a thermal efficiency figure it was necessary to restate the overall material balance so that an elemental balance is obtained for each element in the feed (carbon, hydrogen, nitrogen, sulfur, and oxygen). As a result, the stream flow rate for thermal balance will be slightly different from those used for equipment design.

The major equipment items associated with each unit process area shown on the process block flow diagram were the basis for the capital investment estimate. An example is shown in Figure 6. Oxygen plant and coal preparation areas are excluded, as are the CO_2 removal area, Unit 21, and the sulfur plant, Unit Area 23. The last two are both considered proprietary processes. Unit area equipment sizes and descriptions are shown in Figure 6 by equipment item number designation.

A preliminary fixed capital investment was developed for a grass-roots clean boiler-fuels complex with the principal process units previously described. Necessary ancillary facilities are administration, warehouse, laboratory, change house, cafeteria, and related buildings and equipment; computer capability and communications system; rolling stock (including trucks and automobiles for transport within the confines of the complex); road paving; utilities distribution; and other items required for efficient operation of an industrial complex of this magnitude.

The total major equipment and total constructed costs were developed for each process area; an example is shown in Figure 7. To these were added Home Office engineering, escalation, and sales tax costs, resulting in the total project fixed capital investment cost shown in Table 2. It tabulates major equipment costs and estimated constructed costs for each of the unit areas. Total major equipment cost for all unit areas is \$76.8 million and the factored total construction cost is approximately \$195 million.

Estimated \$310 million for total investment

The estimated total fixed capital investment is \$270 million, including total construction costs, home office engineering, escalation, and sales taxes. In addition, other costs will require the use of funds necessary for land acquisition, rights-of-way, water and mineral rights, and the startup phase. These items are estimated to total approximately \$40 million, as shown on Table 3. The estimated grand total capital requirement for the project is therefore about \$310 million. This is exclusive of interest burden during construction, which depends on the financing method selected.

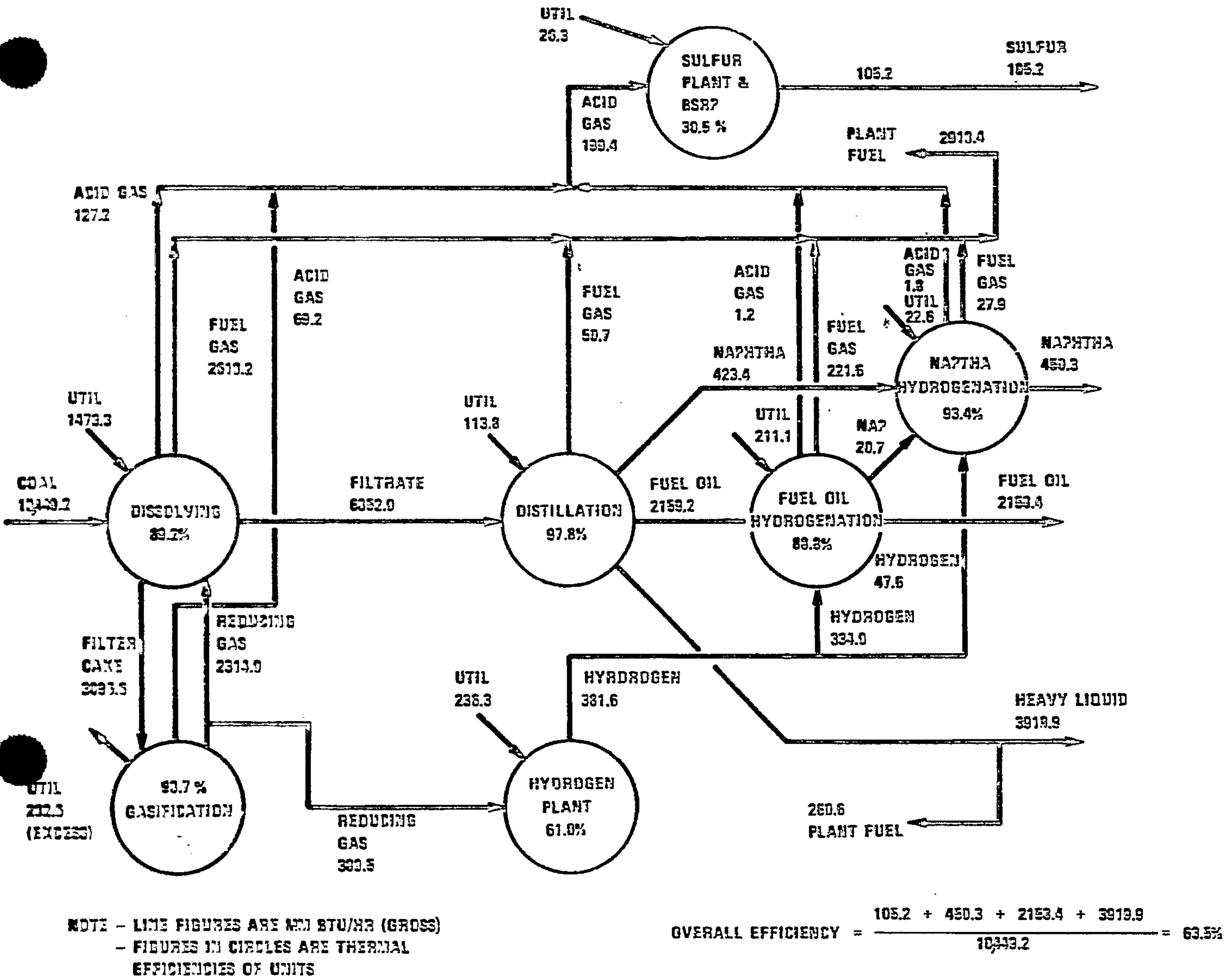

Figure 4. Detailed energy balance.

The demonstration plant fixed capital investment is a preliminary cost estimate for the engineering, design, procurement, and construction of facilities to process 10,000 ton/day of Illinois No. 6 seam coal to produce low-sulfur boiler fuels. The estimate is considered within –5 to +20% accuracy range. It includes the costs of process equipment, construction materials, field labor, field indirect costs, engineering, design and drafting, project management, procurement, supporting services, and escalation. Allowances for instrument checkout and mechanical run-in are also included.

The project is divided into the facilities designated as unit areas, as shown in Table 4. Major process equipment costs were based on preliminary vendor pricing and historical Parsons data. Vendor prices were obtained for some special process equipment where in-house pricing data were not completely applicable. In the case of direct materials, labor, and other costs, estimates for concrete, structural steel, piping, instrumentation, and electrical in total for various unit areas were made by factoring with a multiplier. The factoring method relies on previous job experience for similar process functions, and the multiplier is determined by using the ratio of construction costs to major equipment costs.

The included labor costs reflect current average hourly rates for southern Illinois and expected labor productivity for that area. The estimate is based on a regular work week of five 8-hr days, Monday through Friday. No provision for premium costs for scheduled overtime work is included. However, an allowance for limited nonscheduled overtime is included in the estimating methods employed.

Engineering-construction home office costs were based on management and administration, process and project engineering, construction support, design, drafting, accounting, estimating, scheduling, cost engineering, procurement, expediting, inspection, stenographic, clerical, engineering construction fee, overhead, and out-of-pocket expenses, such as printing, reproduction, computer charges, communications, and travel. Illinois 4% sales tax and/or use tax was included for material and equipment.

The estimate is based on a total project duration of 48 months with an assumed start of engineering January 1, 1974, and construction start about April 1, 1975, with

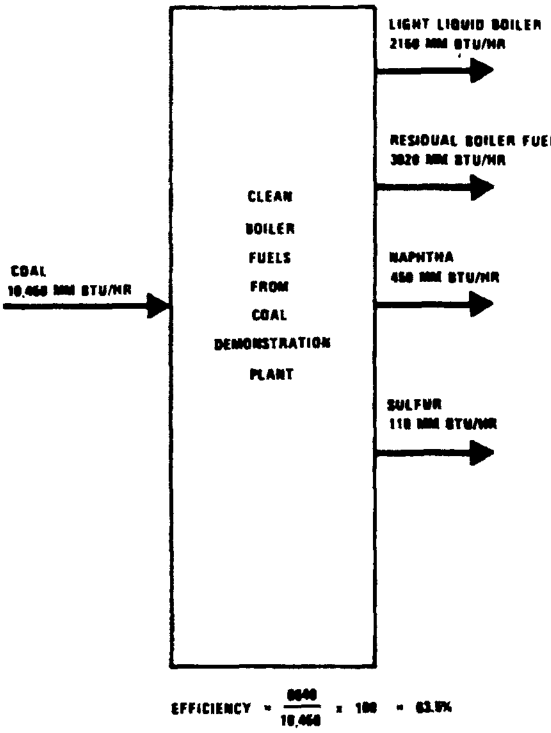

Figure 5. Overall energy balance.

Table 2. Preliminary fixed capital investment summary

Unit	Description	Major Equipment Costs ($)
10	Coal preparation	3,100,000*
11	Coal slurrying and pumping	209,000
12	Coal liquefaction and filtration	21,678,000
13	Dissolver acid gas removal	4,948,000
14	Coal liquefaction product distillation	587,000
15	Fuel oil hydrogenation	5,095,000
16	Naphtha hydrogenation	508,000
17	Fuel gas sulfur removal	488,000
18	Gasification	4,188,000
19	Acid gas removal	1,416,000
20	Shift conversion	1,337,000
21	CO_2 removal	615,000
22	Methanation	102,000
23	Sulfur plant	1,941,000
24	Oxygen plant	12,400,000*
30	Instrument and plant air	172,000
31	Raw water treatment	2,481,000
32	Process waste water treatment	380,000
33	Power generation	10,430,000
35	Product storage	2,231,000
36	Slag removal system	30,000
37	Steam generation	1,512,000
40	General facilities	950,000
	Total	76,798,000
	Total construction cost	194,700,000
	Home office engineering	27,600,000
	Escalation	43,700,000
	Sales tax	4,000,000
	Fixed capital investment	270,000,000

*Package plants (including foundations, piping, etc.)

Table 3. Additional capital investment items

Item	Value $ million
Initial raw materials, catalysts, and chemicals	1
Startup costs	16
Initial working capital	22
Land acquisition, rights-of-way, mineral and water rights	1
Total	40

Table 4. Demonstration plant unit area designations

Unit area	Facility
10	Coal preparation (stockpiling, drying, grinding)
11	Coal slurrying and pumping
12	Coal liquefaction and filtration
13	Dissolver acid gas removal
14	Coal liquefaction product distillation
15	Fuel oil hydrogenation
16	Naphtha hydrogenation
17	Fuel gas sulfur removal
18	Gasification (gasifier and associated equipment)
19	Acid gas removal
20	Shift conversion
21	CO_2 removal
22	Methanation
23	Sulfur plant
24	Oxygen plant
30	Instrument and plant air
31	Raw water treatment (including cooling tower and boiler feedwater facilities)
32	Process waste water treatment
33	Power generation
35	Product storage
36	Slag removal system
37	Steam generation
40	General facilities, on-site

estimated completion and plant startup in late 1977. Escalation has been applied for the specific duration of the project to costs to be incurred for equipment, materials, and labor. No contingency allowance has been applied to this –5 to +20% preliminary estimate.

Startup target date about mid-1978

The project schedule shown in Figure 8 indicates that, for a total contract award by January 1, 1974, the demonstration scale plant can be designed and engineered, the equipment procured and installed, and the plant mechanically complete by the end of calendar year 1977. Plant commissioning and startup would continue into 1978, with partial plant production occurring during the 1978 period. The schedule assumes that all phases of project execution, process design, engineering, procurement, and construction responsibilities are released to a single major contracting firm. It is estimated that allocation of the project into separate engineering and construction responsibilities to more than one subcontractor would extend the overall project completion date to about mid-1978 for plant startup.

UNIT 11 - COAL SLURRYING AND PUMPING

ITEM NO.	DESCRIPTION	SIZE	PRESS/TEMP°F PSIG	MATERIAL/REMARKS
11-1201	Slurry Mix Vessel	18'-0" I.D. x 27'-0"	17/425	SA-285C
11-1202	Slurry Vapor Condensate Drum	5'-0" I.D. x 15'-0"	16/125	SA-285C
11-1203	Slurry Holding Tank	18'-0" I.D. x 27'-0"	17/425	SA-285C
11-1301	Slurry Vapor Condensate	29.9 MMBTU/Hr.	16/446	C.S Shell & Tube
11-1501	Slurry Recirculation Pump	9,000 GPM	35/446	20 Chr. Stl.
11-1551	Slurry Recirculation Pump Spare	9,000 GPM	35/446	20 Chr. Stl.
11-1801	Slurry Vapor Blower	21 SCFM	35/100	C.S. W/C.I. Impeller
11-2001 thru 06	Screw Feeders	16" I.D. x 10'		Link Belt Type C, 5 HP ea.
11-2401	Agitator/11-1201			Chemineer, Model 8HTA30, 30 HP ea.
11-2402	Agitator/11-1203			

UNIT 12 - COAL LIQUEFACTION AND FILTRATION

ITEM NO.	DESCRIPTION	SIZE	PRESS/TEMP°F PSIG	MATERIAL/REMARKS
12-1201	High Pressure Primary Separator	8'-6" I.D. x 17'-0"	1240/840	1-1/4 Cr, 1/2 Mo. Stl.
12-1207	High Pressure Intermediate Flash Drum	12'-0" I.D. x 24'-0"	1220/370	SA-515-70, 1/8 C.A.
12-1208	High Pressure Condensate Flash Drum	13'-0" I.D. x 36'-0"	1175/125	SA-515-70, 1/8 C.A.
12-1209	High Pressure Condensate Surge Drum	9'-0" I.D. x 15'-0"	1175/125	SA-515-70, 1/8 C.A.
12-1210	Intermediate Pressure Liquid Flash Drum	11'-0" I.D. x 22'-0"	500/575	SA-515-70, 1/2 C.A.
12-1211	Intermediate Pressure Vapor Flash Drum	5'-6" I.D. x 16'-0"	495/125	SA-515-70, 1/8 C.A.
12-1212	Low Pressure Liquid Flash Drum	15'-0" I.D. x 30'-0"	150/575	SA-515-70, 1/8 C.A.
12-1213	Filtrate Flash Drum	16'-0" I.D. x 20'-0"	110/575	SA-515-70, 1/8 C.A.
12-1214	Filtrate Vapor Flash Drum	15'-0" I.D. x 20'-0"	105/125	SA-515-70, 1/8 C.A.
12-1215	Solvent Flash Drum	12'-0" I.D. x 24'-0"	16/570	SA-385C
12-1216	Solvent Vapor Flash Drum	5'-0" I.D. x 15'-0"	21/125	SA-385C
12-1217	Water Surge Drum	5'-0" I.D. x 12'-0"	350/125	SA-515-70
12-1218	Make Up Gas 1st Stage Condensate Drum	10'-0" I.D. x 12'-0"	375/125	SA-515-70
12-1219	Make Up Gas 2nd Stage Condensate Drum	7'-6" I.D. x 12'-0"	735/125	SA-515-70
12-1220	Solvent Vapor 1st Stage Condensate Drum	3'-0" I.D. x 8'-0"	27/125	SA-385C
12-1221	Solvent Vapor 2nd Stage Condensate Drum	3'-0" I.D. x 8'-0"	116/125	SA-385C
12-1222	Precoat Slurry Vessel	12'-0" I.D. x 22'-0"	32/518	SA-385C
12-1223	Filter Drain Vessel	5'-0" I.D. x 10'-0"	550/300	SA-515-70

Figure 6. Example of equipment list.

Account Code	Description	Coal Preparation Unit 10	Coal Slurrying and Pumping Unit 11	Coal Liquefaction and Filtration Unit 12	Dissolver Acid Gas Removal Unit 13	Coal Liquefaction and Product Distillation Unit 14	Fuel Oil Hydro-genation Unit 15	Naphtha Hydro-genation Unit 16	Fuel Gas Sulfur Removal Unit 17
		Materials and Expense	Materials and Expense	Materials and Expense	Materials and Expense	Materials and Expense	Materials and Expense	Materials and Expense	Materials and Expense
1100	Columns				2,550,000	159,000	29,000	22,000	126,000
1200	Vessels		126,000	3,290,000	192,000	18,000	2,312,000	116,000	16,000
1300	Heat Exchangers and Condensers		22,000	2,995,000	1,284,000	142,000	1,105,000	165,000	184,000
1400	Furnaces, Heaters			4,900,000		226,000	182,000	71,000	
1500	Pumps and Drivers		41,000	2,008,000	603,000	42,000	197,000	39,000	94,000
1600	Boilers								
1700	Cooling Towers								
1800	Compressors and Blowers		1,000	2,435,000			1,270,000	95,000	
1900	Storage Tanks			62,000	157,000				10,000
2000	Materials Han-dling Equipment		9,000	44,000					
2200	Separation Equipment				45,000				
2300	Package Plants	3,100,000							
2400	Agitators, Mixers and Blenders		10,000	4,000					
2500	Reactors (All Types)			4,740,000					
2800	Other Major Equipment			1,200,000	117,000				45,000
	Total Major Equipment Cost	3,100,000	209,000	21,678,000	4,948,000	587,000	5,095,000	508,000	488,000

Figure 7. Example of detailed unit cost tabulation.

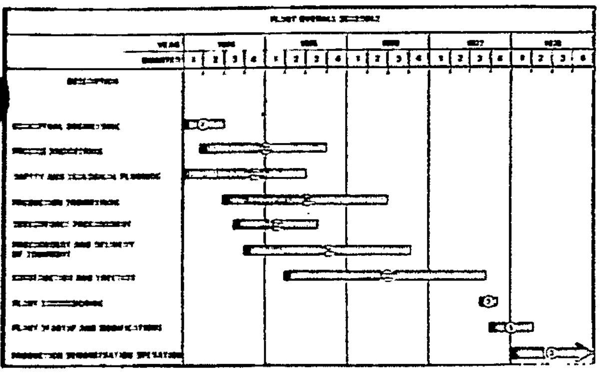

Figure 8. Project schedule.

The estimated rate of project expenditures by semi-annual periods is presented in Figure 9 and the cumulative expenditures are shown in Figure 10. The fund requirement schedule, as shown, does not include interest charges for use of the estimated fixed capital investment of $270 million. The fund drawdown schedule reflects the rates of fund expenditures as the project moves from conceptual engineering through detailed mechanical engineering, procurement, and construction phases based upon the project schedule previously shown.

Preliminary conclusions

While considerable data are available for coal liquefaction, the specific conditions of recycle of unfiltered dissolver product to form the feed coal slurry is based upon relatively few data runs. Therefore, additional work is needed to assure design yields and operability of the process. The basis used for this design is essentially that established by the process development contractor. Critical parameters were:

1. Recycle unfiltered liquid effluent from the dissolvers.
2. Hydrogen consumption for the dissolving section is 3 wt.-% of the coal feed.
3. Residence time for liquid in the preheater and dissolver should be 1 hr.
4. Use syngas (hydrogen plus carbon monoxide) to supply hydrogen requirements of the dissolving operation.
5. Conversion, solid to liquid, of coal in the dissolver is 91%.
6. Use filtration on net dissolver product to remove undissolved solids from the product. Filter cake shall contain equal weights of undissolved solid and liquid product.
7. Preheater outlet and dissolver temperatures shall be 900°F and 840°F, respectively.
8. Solvent recycle rate shall be twice the weight of the coal feed.

The limited laboratory results indicate that the use of unfiltered solvent is attractive for both yield and character of liquid product from coal. The demonstration plant is designed on this basis. As a consequence of the recycle of undissolved material, the resultant product is lower in boiling point, is liquid at ambient temperatures, and is lower in sulfur content than if the recycle solvent were free of solids. A result of use of this scheme, *vis-a-vis* use of filtered recycle feed to the dissolver, is that the hydrogen input to the coal is higher, tending to lower the plant's thermal efficiency.

Additional data should be developed to define the residence time required to achieve the liquefaction of the coal. It is logical that residence time could be reduced if higher temperatures and possibly higher pressures were employed at the dissolvers. Sufficient data should be ob-

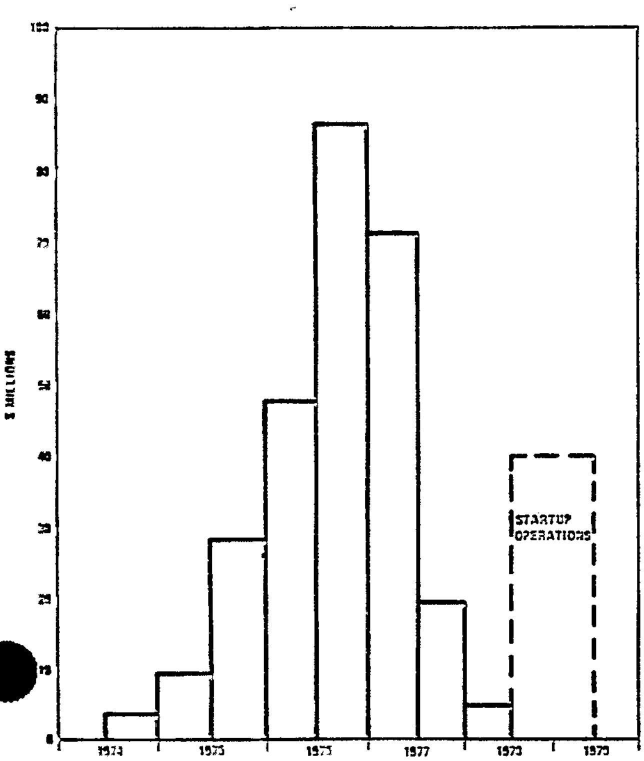

Figure 9. Fund drawdown schedule.

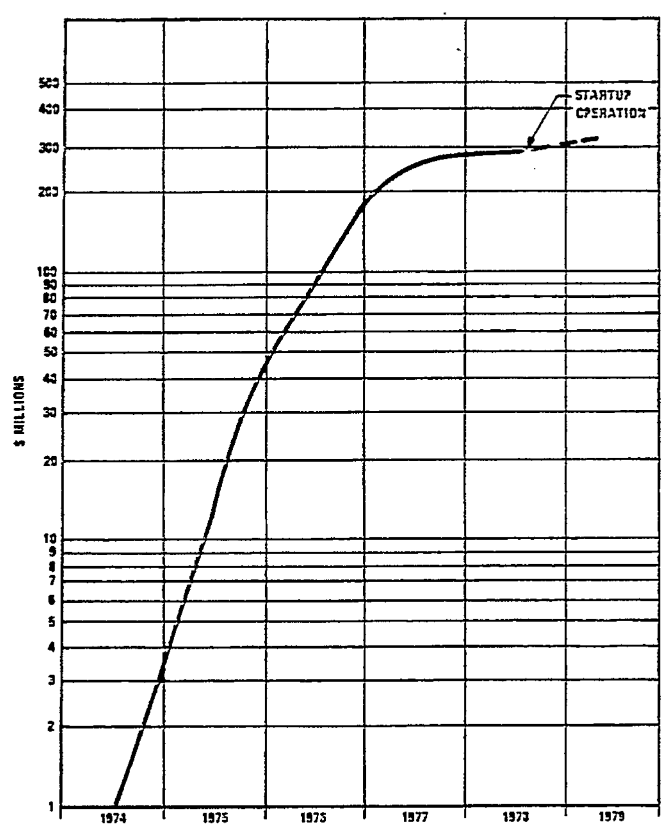

Figure 10. Fund drawdown schedule, cumulative.

tained to accurately establish the relationship between temperature and residence time.

It is most critical that experiments be made to achieve equilibrium with regard to recycle liquid composition and quantity. Since prediction of yield, product quality, and ease of filtration are dependent upon accurate laboratory results, more laboratory or pilot plant work is required in this area.

Runs should be made where equilibrium recycle liquid composition is attained with hydrogen gas and then syngas. It would be valuable to extend these data to include the effect of higher temperature and shorter residence times because the liquefaction section is a high capital investment area. More specifically, future laboratory experiments should demonstrate the effects of pressure and gas rate on conversion.

Gasification unit design is principally based upon suspension flow technology modified to maximize syngas production. Heat considerations that are a direct result of the mechanical design of the gasifier must be resolved. Heat loss value used in the design prepared for this report is 270 Btu./lb. of coal equivalent. Reported values from the various sources range from a heat loss of 55 to 1,200 Btu./lb. of coal. With higher heat loss, more oxygen is required and, consequently, more carbon dioxide is produced. This question needs to be resolved before finalizing the design of the gasifier and its supporting facilities.

The amount of liquid that must be carried with the filter cake to make it pumpable and injectable into the gasifier should be determined. Laboratory experiments should be conducted using mixtures of dry filter cake and filtrate at near pumping temperatures to determine the physical properties and flow and injection characteristics of the material.

General conditions for desulfurization units have been taken from data on COED oil. The severity of desulfurization and the feed stock are less demanding in this design than would be the case for full-range COED oil. The technology for this process is generally known but specific conditions for this stock are not precisely known. To assure reliability and performance of such a unit, actual feed stock for the unit should be derived from pilot plant operation and made available for at least a bench-scale test on the catalyst to be used. Specifically, laboratory testing should be conducted to determine to what extent organometallic compounds are present in the feed and in what boiling range of the feed these materials exist.

No provision has been made in this design for the presence of organometallic compounds and their detrimental effect on catalyst performance and life, because the material desulfurized in this design boils below the temperature where these compounds would be expected to appear in petroleum-derived liquids.

The detailed design of the proposed demonstration plant would be in progress while the pilot plant at Tacoma is in operation. It is possible that many of the operating and quality questions can be answered and/or demonstrated by the performance of Tacoma, and we hope that the schedule of the Tacoma pilot plant can be adjusted toward support of the demonstration plant design.

During the design assignment, analysis showed that it is possible to produce desulfurized liquid fuels exclusively when using an alternative approach to syngas production. The current preliminary design employs gasification of a coal residue from the liquefaction plant for this purpose. One alternative is to use the offgases from the liquefaction plant for syngas production rather than for plant fuel. The coal residue could then be gasified, possibly with air, produce desulfurized low-Btu fuel gas for captive use. The heating values produced by this scheme can be absorbed in the total plant design without introducing a fuel imbalance.

The design criteria did not permit purchase of hydrocarbon feedstocks for plant startup. Also, the plan is to include demonstration of production of syngas by gasification of coal or a coal-sourced solid in the design. These objectives could be achieved using the plant modification, for syngas described above. With this modification, the gasification operation is removed from the main production line and becomes a service plant producing fuel gas at low pressure. Such a service plant can be designed with as many parallel trains as are required to support a desired design service factor. #

O'Hara

Jentz

Rippee

Mills